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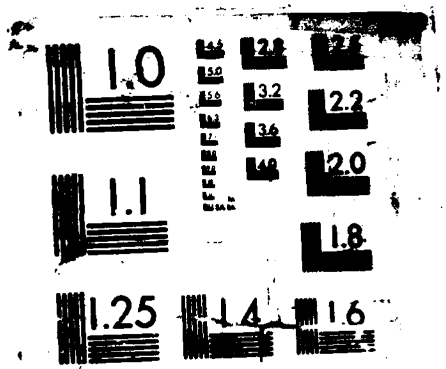


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# NAVAL POSTGRADUATE SCHOOL

Monterey, California



# THESIS

DYNAMIC POSITIONING AT SEA
USING THE GLOBAL POSITIONING SYSTEM

by

Augusto M. Ezequiel

June 1987

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|---|---|
| Co-Advisor | Narendra Saxena |
| Co-Advisor | Stevens P. Tucker |

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Dynamic positioning of a moving platform is analyzed using data from the Global Positioning System (GPS) acquired in Phase II of the Seafloor Benchmark Experiment on R/V Point Sur in August 1986. GPS position determinations are compared to simultaneous Mini-Ranger fixes.

The GPS positions computed using only broadcast ephemeris data were within 20 m from the Mini-Ranger fixes when data from four satellites were used and within 30 m when data from three satellites and a geoidal height constraint were used. It was found that the position accuracy is degraded when data from a satellite reaching culmination is used.


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# Dynamic Positioning at Sea Using the Global Positioning System

by

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Portuguese Naval Academy, 1975

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN HYDROGRAPHIC SCIENCES

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ABSTRACT

Dynamic positioning of a moving platform is analyzed using data from the Global Positioning System (GPS) acquired in Phase II of the *Seafloor Benchmark* Experiment on R/V Point Sur in August 1986. GPS position determinations are compared to simultaneous Mini-Ranger fixes.

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## THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been tested for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logical errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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# ACKNOWLEDGEMENTS

The author expresses his appreciation to Dr. Stevens Tucker and Dr. Narendra Saxena for their support and advice in this project, making it a worthwhile learning experience. I would also would like to thank my wife, Conceição and son, Diogo whose love and support encouraged me to complete this work.

# I. INTRODUCTION

The Seafloor Benchmark Experiment, a project of the Hydrographic Sciences Group of the Oceanography Department at the Naval Postgraduate School (NPS), was initiated in 1984 with a goal to establish stations on the seafloor in real-time with geodetic accuracy (Saxena, 1982). The first experiment (Phase I), conducted in May 1985, included a configuration of four benchmarks on the seafloor (Spielvogel et al., 1987). Further study indicated a sizeable improvement in the positional accuracy of the inner stations as compared to the accuracy of the outer stations of a larger net configuration (Kumar and Saxena, 1985). For this reason, during the Phase II experiment in August 1986, a nine-station net configuration was used (Kumar, 1986). Three types of GPS receivers and a Mini-Ranger (MR) Falcon system were used to determine the position of the R/V Point Sur.

Keeping the goal of establishing and continuing GPS research at NPS, Brown (1986) established the Texas Instruments 4100 GEOSTAR GPS software, written by the Naval Surface Weapons Center for their CDC Cyber 865 computer, on the NPS IBM-3033 computer. Brown was able to validate the modified software using static position data, but not the KALMN2 program which uses dynamic position data.

The main objective of this thesis is to determine the positions of a dynamic platform using GPS and to compare them with MR Falcon-determined positions. Other objectives were to install software for processing the raw data from cassettes to FIC (Floating-Integer-Character) format, modify the KALMN2 program and validate it using Phase II data. Programs to plot and analyze the continuous ship positions by GPS and by MR Falcon were also written.

The data used in this thesis were acquired during Phase II of the Experiment. The GPS data are limited to those collected by the TI-4100 receiver from NSWC installed on board of the R/V Point Sur. The day chosen for analysis was 16 August 1986, since adequate pitch and roll data are available for that day.

# II. INSTRUMENTATION

## A. POSITIONING SYSTEMS

### 1. GPS receivers

During the experiment, the following GPS receivers belonging to several agencies and companies were installed on the R/V Point Sur:

- TI-4100 receiver from Naval Surface Weapons Centers (NSWC)
- TI-4100 receiver from National Ocean Survey (NOS)
- Eagle Mini-Ranger receiver from Motorola, Inc.
- Trimble 4000A from Trimble Navigation

There were shore based GPS receivers at the following stations:

*Beach Lab*

- TI-4100 from Pacific Missile Test Center (PMTC)
- Trimble 4000A from Trimble Navigation

*Ferrier*

- Eagle Mini-Ranger from Motorola Inc.

*Dome*

- Magnavox Manpack from GPS Joint Program Office.

### 2. Other positioning System

For navigation and positioning on board were a MR Falcon system from Motorola, Inc., and a Loran-C receiver.

## B. OTHER SYSTEMS

An acoustic positioning system from Oceano Instruments to acquire acoustic ranges (Kuo,1985) was installed on the R/V Point Sur; it also gives the position of the ship in relation to the bottom benchmarks (acoustic transponders) and can be integrated with a satellite receiver for computation of their positions using the GPS coordinates of the ship's acoustic transducer.

In order to allow for corrections due to the pitch and roll of the ship, there was a data acquisition system, based on an HP9826 computer, to collect pitch, roll and heading data every second. Due to interfacing problems there was no possibility of logging heading data. The ship's Data Acquisition System (SDAS) collected, among other data, the ship's heading with a sampling period of about 19 s.

## C. ANTENNAS AND TRANSDUCER POSITIONS

The antenna of the MR Falcon was mounted on the mast of the ship in order to increase its range. The antenna of the TI-4100 from NOS was installed close to the MR Falcon antenna. All the other GPS antennas were mounted on an elevated wooden table above the ship's laboratories and close to the transducer position (Figure 2.1).

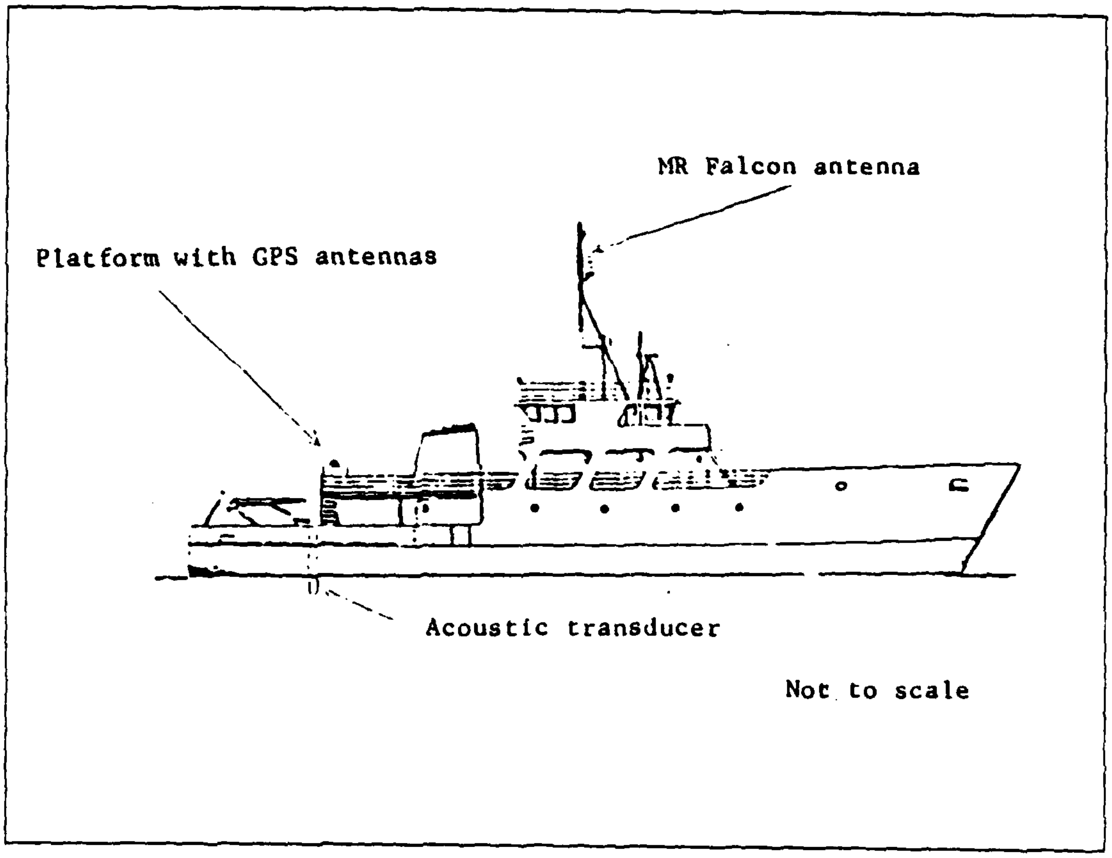



Figure 2.1 Relative positions of antennas and transducer.

# III. DATA PROCESSING

## A. COORDINATE SYSTEM

### 1. Parameters

In order to compare the positional accuracies of the TI-4100 GPS receiver with the Mini-Ranger (MR) Falcon, computations were made in a single coordinate system.

Although there was a Doppler survey to find the WGS 72 coordinates of all control stations used, due to the impossibility of setting a station over Dome Ecc, the site for one of the MR Falcon shore stations, the WGS 72 coordinates of nearby station Dome, 68 m away, were obtained. During the Phase II experiment, GPS provided coordinates in the WGS 72 system (Bomford, 1980, Sepplin, 1974), although it converted to WGS 84 on 1 January 1987 (Decker, 1986).

The coordinates of Dome were computed in NAD 27 and then transferred to Dome Ecc. The coordinates of Dome Ecc were converted from NAD 27 to WGS 72 in order to compute directly the ship positions in this system, avoiding the problem of converting each position individually.

The subroutines used for converting geodetic coordinates from WGS 72 to Universal Transverse Mercator (UTM) and vice-versa wer written in Fortran and are based on Basic subroutines used by DMA for an HP9826 desktop computer. A cross check was made which revealed a maximum conversion error of 0.01 m, which is well within the accuracy limits of the system and, hence, does not affect the analysis of the data processed.

The following parameters were used:

WGS72

| | |
|---|---|
| Semi major axis : | 6,378,135 m |
| Flattening : | 1/298.26 |

UTM projection

| | |
|---|---|
| Central meridian: | 123° 00' 00" W |

If this package of subroutines is used for any location other than the area of the Seafloor Benchmark Phase II, the UTM parameters must be changed in order to get the correct conversions.

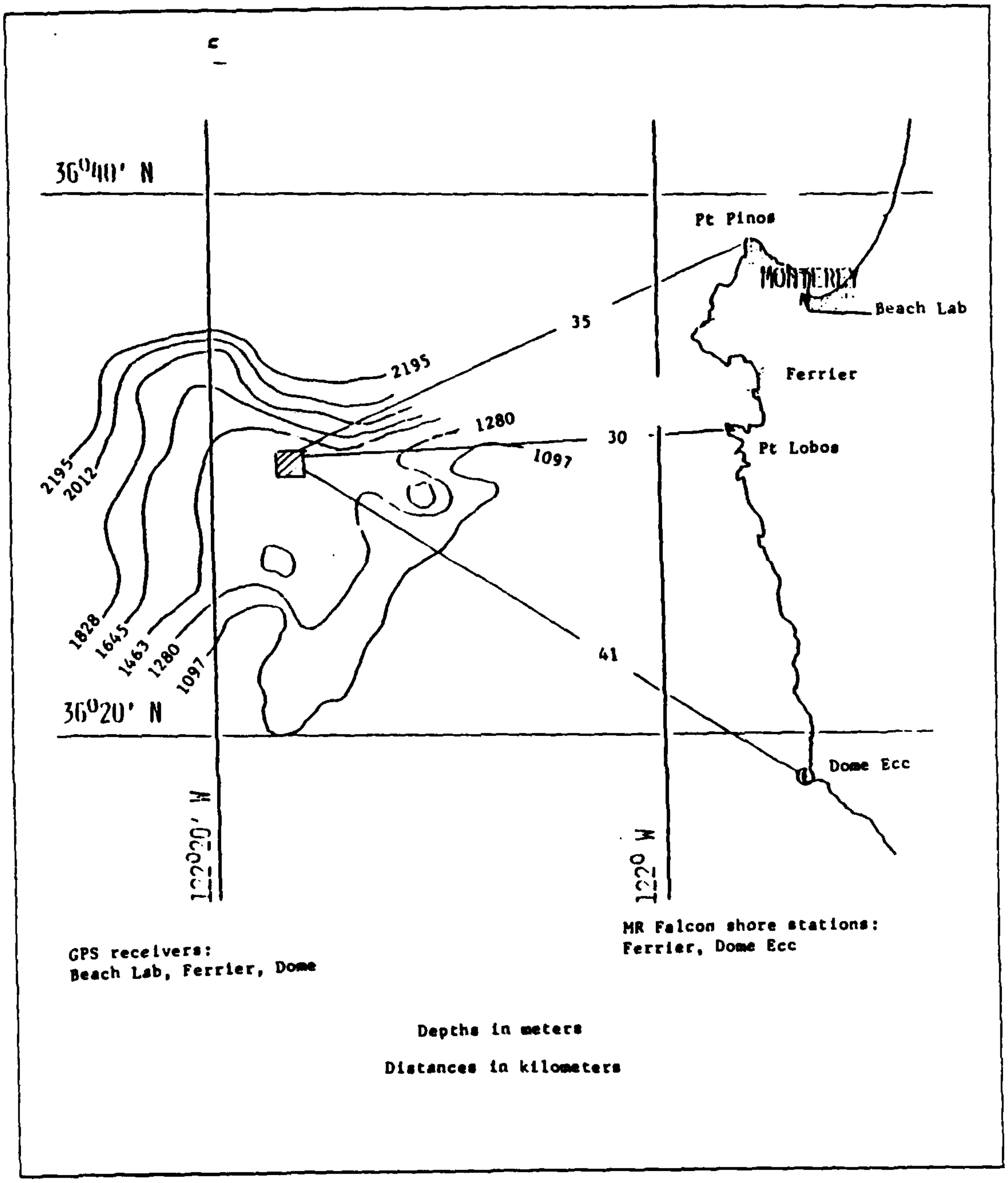



Figure 3.1 Area of the experiment.

## 2. Coordinates of stations

The two shore stations were located on high points along the coast (Figure 3.1). Their locations and coordinates in WGS 72 are as follows:

*Ferrier*

Latitude 36° 33′ 53″.748 N

Longitude 121° 53′ 52″.939 W

*Dome Ecc*

Latitude 36° 18′ 20″.897 N

Longitude 121° 54′ 00″.594 W

The elevations of the different antennas were set in the Mini-Ranger receiver and the measured slant distances were converted
to appropriate horizontal distances by the receiver system during data acquisition.

## B. REDUCTIONS OF POSITIONS TO THE TRANSDUCER

### 1. Offsets of transducer relative to antennas

Since the two antennas, namely the MR Falcon antenna near the top of the mast and the TI-4100 antenna on the elevated table above the lab on the R/V Point Sur, were at different locations, a common point had to be chosen to compare both systems. The acoustic transducer mounted beneath the hull was chosen as a common point, which was used for further integration with the acoustic data, to compute the position of the Seafloor Benchmarks.

For data reduction there was a need for pitch, roll and ship's heading data. While the existing pitch and roll data were sampled with a period of 1 s, the ship's heading was sampled with a period of about 19 s. Computed headings were tried to improve the rate but tests indicated that the real data, even with a low sampling rate was better than the computed. The method used to compute the heading is described in Section C.3.

The geometric offsets between the MR Falcon, TI-4100 antenna and the acoustic underwater transducer were computed using a right-handed coordinate system centered in each antenna, and having the Y axis oriented towards the bow, the X axis to starboard and the Z axis towards the zenith. Using this convention, all offsets of the transducer are negative. Using the formulas developed in the next section, the corrections for pitch, roll and heading data were computed and applied.

For the MR Falcon positions only horizontal corrections were applied, since the positions are computed in a two-dimensional system. For the GPS positions the corrections were applied to all three coordinates.

For both types of positions the coordinates are converted to UTM, corrected and converted back to WGS 72. For the GPS positions the Z correction is applied to the geoidal height.

The following offsets were measured and computed by Prof. Tucker and Mr James Cherry, and changed to the above format.

Transducer offsets relative to the GPS antenna :

XOFF = -4.268 m

YOFF = -2.955 m

ZOFF = -9.505 m

Transducer offsets relative to the MR FALCON antenna :

XOFF = -5.345 m

YOFF = -9.453 m

ZOFF = -16.152 m

The course was computed in a range 0° to 360°, and the pitch and roll data were stored in a range -90° to +90°; following this convention the roll is positive when the port is up and the pitch positive when the bow is down. The sign of roll was changed to conform with the mathematical model described next.

### 2. Math model

The method to compute the correction to the coordinates is based on a seven-parameter transformation described in Moffitt and Mikhail (1980), so successive rotations of the vector defined by XOFF, YOFF and ZOFF, give the corrections to the coordinates illustrated in Figure 3.2.

The rotation matrices are defined as follows:

$$M_p = \begin{vmatrix} 1 & 0 & 0 \\ 0 & \cos(PITCH) & \sin(PITCH) \\ 0 & -\sin(PITCH) & \cos(PITCH) \end{vmatrix}$$

$$M_r = \begin{vmatrix} \cos(ROLL) & 0 & -\sin(ROLL) \\ 0 & 1 & 0 \\ \sin(ROLL) & 0 & \cos(ROLL) \end{vmatrix}$$

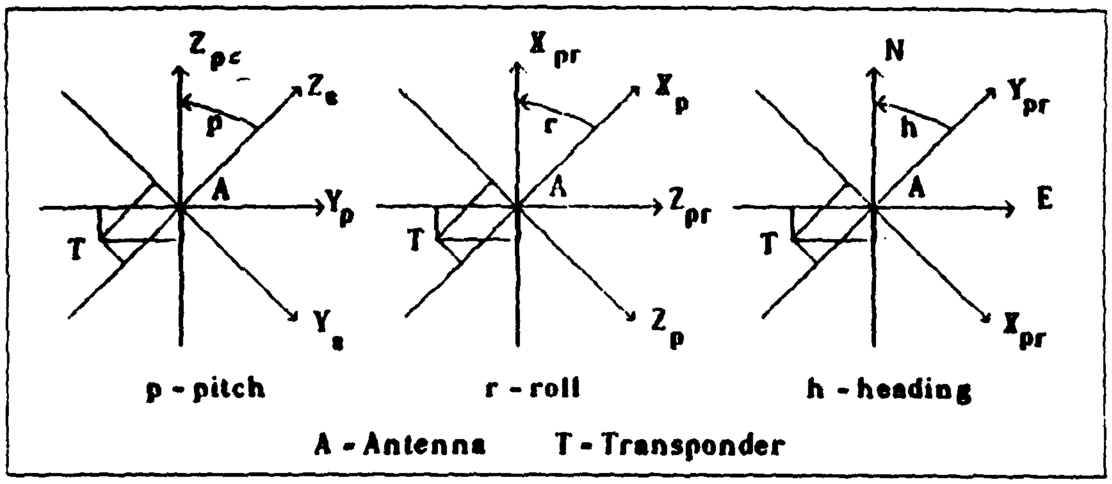



Figure 3.2 Rotation of axis.

$$M_h = \begin{vmatrix} \cos(\text{HEADING}) & \sin(\text{HEADING}) & 0 \\ -\sin(\text{HEADING}) & \cos(\text{HEADING}) & 0 \\ 0 & 0 & 1 \end{vmatrix}$$

The orientation matrix is defined by the following equation:

$$M_o = M_p M_r M_h \qquad \text{(eqn 3.1)}$$

and the corrections are computed by multiplying the orientation matrix by the offset vector, to get the following equations:

$$\begin{aligned} DX = {} & \text{XOFF} \cos(\text{ROLL}) \cos(\text{HEADING}) + \\ & \text{YOFF} \{\cos(\text{PITCH}) \sin(\text{HEADING}) + \\ & \sin(\text{PITCH}) \sin(\text{ROLL}) \cos(\text{HEADING})\} + \\ & \text{ZOFF} \{\sin(\text{PITCH}) \sin(\text{HEADING}) - \\ & \cos(\text{PITCH}) \sin(\text{ROLL}) \cos(\text{HEADING})\} \end{aligned} \qquad \text{(eqn 3.2)}$$

$$DY = XOFF\cos(ROLL)\sin(HEADING)(-1.) + YOFF\{\cos(PITCH)\cos(HEADING) - \sin(PITCH)\sin(ROLL)\sin(HEADING)\} + ZOFF\{\sin(PITCH)\cos(HEADING) + \cos(PITCH)\sin(ROLL)\sin(HEADING)\} \quad \text{(eqn 3.3)}$$

$$DZ = XOFF\sin(ROLL) - YOFF\sin(PITCH)\cos(ROLL) + ZOFF\cos(PITCH)\cos(ROLL) \quad \text{(eqn 3.4)}$$

## C. FALCON MINI-RANGER DATA PROCESSING

### 1. Error of system

The MR Falcon was used during the cruise for navigation and positioning. In post-processing it is used to evaluate GPS data. Since the Mini-Ranger is a system frequently tested and used, its error is known to be ± 3 m (Laurila, 1976; Munson, 1977).

It would be better to have had more than two lines of position (LOP) to allow a minimization of the error in the computation of the Mini-Ranger position and also to allow a smoothing of the data in places where the data gets noisy as was seen in post processing. In Figure 3.3 it is possible to see the areas where the data is noisy and to see the small jumps characteristic of the system.

### 2. Antenna positions

For computing the antenna positions the coordinates of the shore stations were converted to WGS 72 UTM, and then each position was computed in the WGS 72 UTM projection. The subroutine used to compute the positions was picked from program UCOMPS, a utility package used in the Hydrographic Sciences Group of the Oceanography Department.

### 3. Heading Calculation

As mentioned previously, the ship's heading was needed to compute the transducer's position, but there was no data available with the 1-s periodicity needed, so headings were calculated from Mini-Ranger data. The calculation of the ship's headings was made during the computation of the two antenna positions and kept on a separate file. These computed headings were affected by the pitch and roll of the ship and also by the noisy data of the Mini-Ranger.

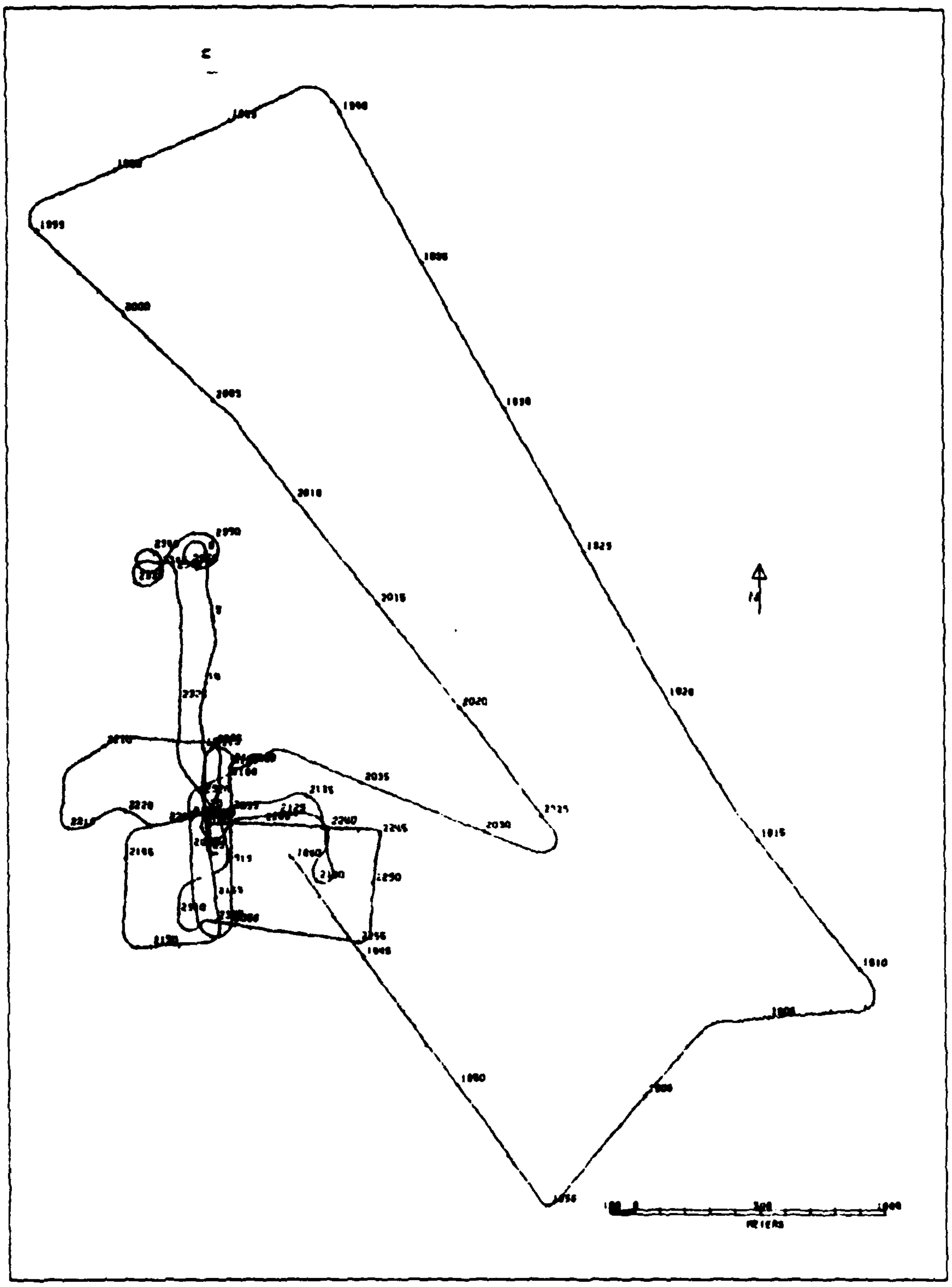


Figure 3.3 Plot of ship's track using MR Falcon data.

Some trials were made using different running averages for smoothing the computed heading in order to get a course close to reality. It was found that the courses obtained, even if filtered by a running average, oscillated and hence were not suitable for this analysis.

### 4. Transducer positions

The transducer positions were computed using the model described in Section B. The pitch and roll data used were sampled with a periodicity of 1 s most of the time when there was positioning data. The ship's heading was sampled with a periodicity of from 19 s to 1 minute. Although tests were made in order to compute the heading, as stated in the previous section it was decided to use recorded data, constraining the analysis to periods of constant course.

### 5. Programs. Inputs and outputs

During the development of the programs many more routines were written than mentioned here. In order to make the use of the programs easy, the total number of programs to process the MR Falcon data was reduced to four.

A unique format for the different position files was defined, allowing only one plotting program in which the user must change the title according to the type of positions plotted.

| | |
|---|---|
| Program: | FALCON |
| Input: | Month, day, year, hour, minutes, seconds (date time tag), code1, range1, strength1, code1, range2, strength2 |
| Output: | Listing with date time tag and geographic positions |
| | File with date time tag and geographic positions |
| | File with date time tag and rough course |
| Source: | See Appendix A |

| | |
|---|---|
| **Program:** | COURSE SMOOTH |
| Input: | File with date time tag and rough course |
| Output: | File with date time tag and smooth course |
| | Listing with date time tag and smooth course |
| Source: | See Appendix B |

| | |
|---|---|
| Program: | TRANSDUC FALCON |
| Input: | File date time tag and geographic positions of antenna |
| Output: | File with date time tag and geographic positions of transducer<br>Optional listing with date time tag and geographic positions of transducer |
| Source: | See Appendix C |

| | |
|---|---|
| Program: | PLOT |
| Input: | File with date time tag and geographic positions |
| Output: | Plot with track of the ship in UTM projection |
| Source: | See Appendix D |

All files are in free format, and, if for by any reason a fixed format is needed, the user should change the programs to get the output desired. The MR Falcon data were originally on floppy disks in HP9816 format. A program was written in Basic in order to convert and write the data onto a 9-track magnetic tape. The transfer of data to mass storage on the NPS IBM mainframe computer and data manipulation were made using existing procedures for the mainframe (Favorite, 1986; Mar, 1984).

The scale and the area of the plot are fixed for the particular area of the Benchmark Experiment but may be changed in the program; thus any proportional size can be obtained by changing the control card as is explained in the manual (W.R. Church Computer Center, 1981).

As the plot program can be used for plotting the outputs of different programs, the title should be changed accordingly, leaving the appropriate lines uncommented. An hour-minute tag is plotted every 5 minutes.

## D. GPS DATA PROCESSING

### 1. Reading the TI-4100 cassettes

#### *a. System configuration*

The data from the TI-4100 receiver is recorded on digital cassettes in a format not directly compatible with the existing programs at NPS. To read and decode the data, it was necessary to purchase a MEMTEC cassette terminal (Model 5450XL) and obtain the appropriate software from the Applied Research Laboratories (ARL) of the University of Texas at Austin. The MEMTEC cassette reader was connected to an IBM PC having a hard disk of 20 Mb (Megabytes), a modem and a math co-processor.

Preliminary tests made to verify the software and hardware connections of the tape deck with the IBM PC indicated good results. During the tests it was found that the format of the final output of this package was not the same as defined previously by Scott and Peters (1983) but was in a new format, FIC, where each block is organized in a structured way with control records followed in order by all floating type data, integer type data and character type data. The first program, CON9TR, a part of the library installed by Brown (1986) in the SEF (Standard Exchange Format), was replaced by a new program using the FIC format.

***b. Reading cassettes to disk***

Each cassette is dumped to disk using the program MFERD. The operation takes about 20 minutes, and the file created fits on one floppy disk which can be kept for raw data backup.

***c. Converting the data***

The binary image of the cassette is then converted to a FIC format file using the program GS2FIC, which takes about 20 minutes. This format is suitable for processing in the IBM-PC with appropriate software to be developed.

In order to transfer these files to the main frame or other computer, it is necessary to run a program FICFICA that converts the FIC files to an ASCII, format where the data is organized in 80-column records. This operation takes about 30 minutes. and the file created by this program can be dumped to a magnetic tape or sent to a host computer.

The files created by these two programs cannot be stored on a normal floppy disk and were erased as soon as the data was on the mass storage of the mainframe and tested.

***d. Transfer to the mainframe***

The transfer of the files to the mainframe was done using a micro-computer connected via modem to the main frame. A terminal emulator distributed by the NPS Computer Center, SIMPC, simplifies the transfer of files (Simware Inc, 1984).

Each file, corresponding to one cassette, was sent to a disk. This operation took about 3.5 hours, and sometimes the transfer was stopped in the middle. When this happened the transfer had to be started from the beginning.

Each file has around 15000 lines and occupies about 65% of an A-disk. Using an extra disk every file was converted to a job format in order to transfer it to

mass storage. The data were sent to a member of a partition data set where all cassettes were stored.

2. **Conversion of formats**

After a study of the FIC format, the input of KALMN2 program, and the program CON9TR, a program was written called CVFICA, which had, after some debuging and improvements, a final form that fulfilled the needs for processing the data for this thesis.

CVFICA decodes each FICA block, producing two files and a listing of warnings and general information. One file contains the data to be processed by the KALMN2 program and the other has the positions computed by the GESAR software installed in the receiver.

In the present version of the program the pseudo-ranges and other tracking information are stored only after the navigational data for the desired number of satellites is in the output file, since this data is needed to compute the positions in the Navigational Mode. It is very easy to change this program to process the data using the precise ephemeris. The program flags as bad the data that belong to a Space Vehicle (SV) whose data does not correspond to the existing SV identification in that tracer. The data are also flagged as bad when the status vector has any value other than zero.

The program is able to convert the following data block types:

101 - GESAR Versions 1.0+ Input data,
3 - GESAR solutions,
6 - Tracking data,
8 - Tracking configuration,
109 - Navigation Message record as transmited,
9 - De-blocked subframes 1-3 from block 109
11 - Receiver error block,
13 - Tape header/trailor.

According to the CVFICA program any other block is read and dumped to the listing with a warning saying that the program was not able to handle it. No such warning was found after using the program with data from 10 cassettes.

The listing also indicates when the navigational data for each satellite is received in order to give to the user the status of the constellation of satellites.

As this program outputs the GESAR position solutions and the data to the KALMN2 program into data set files, these must be created prior to running the program.

A control file is used to pass to the program information such as two lines for the title of the listing and the starting date of the GPS week. The starting date allows the conversion of the time tag in seconds to a date time tag. The program does not work with data that crosses the one-week limit.

3. **Program information**

| | |
|---|---|
| Program: | CVFICA |
| Input: | FICA files without the first two comment lines |
| | Control file with the title and starting date of GPS week (Appendix J) |
| Output: | File with GESAR solutions |
| | File in NSWC format (input to KALMN program) |
| | Listing with warnings and general information |
| Source: | See Appendix E |

4. **Computation of positions**

***a. Problems found***

When starting to use the Kalman filter program (Brown, 1986) for processing the GPS data some difficulties were encountered, either due to the replacement of the CON9TR program by an equivalent one or by errors existing in the program KALMN2. The first problems were caused by the different units used in the ARL and NSWC software which were a consequence of the lack of documentation during the development of the program CVFICA; these problems were easily found and solved. The last problems took a long time to find, not only due to the complexity of the program, but also due to the nonexistence of processed data to check the results. A big effort was made in order to correct all errors, but only when two cassettes were sent to NSWC and processed there were all errors removed from the processing. It was found that the last two major errors were due to causes external to the KALMN2 program, one an error in the ARL software that affected the ambient temperature by a factor of 10 and caused an excessive tropospheric correction and the other a bad constant in the control file of the KALMN2 program.

*b. Changes made*

In addition to the corrections, some changes were made to improve the outputs. Now the program prints a date time tag just prior to all outputs labeled with time tag in seconds of GPS week. A title is printed as a header of the output listing. Other small changes were made to improve the code. All changes were made carefully, and the programs were throughly tested.

*c. Data processing*

After inserting data from ten TI-4100 cassettes into the mass storage, a control file for the KALMN2 program was made (Brown, 1986). For an initial approximate position, the position of the receiver based on the GESAR solutions with the time tag closest to the starting time was used for the data processing. For the receiver time bias, an iterative procedure was used; thus, the data were processed using a value, starting with zero, that was replaced by one listed in the outputs of the KALMN2 program when the computed positions were close to the predicted ones.

Due to the good initial results of the test runs with certain satellite configurations, further tests were investigated for the different types of solutions.

The value of -37 m was used as geoidal height in order to constrain the positions to the geoid when using data from less than four satellites or when forced by the control file. This value was obtained by interpolation on a chart (Blaha et al., 1986) and corrected for the antenna height above sea level, giving a corrected value of -31 m. The control file was set up in such a way as to save the positions on another file. The broadcast ephemeris was used, as the precise ephemeris was not available when the data were processed.

*d. Math model*

To compute position, the program uses the pseudo-ranges corrected for the various factors affecting them and an eight-state Kalman filter (Brown, 1986).

*e. Program information*

| | |
|---|---|
| Program : | $^{c}$KALMN2 |
| Input: | File in NSWC format produced by the program CVFICA |
| | Control file as defined by Brown (1986)(Appendix I) |
| | Control file with the title and starting date of GPS week |
| Output: | Listing with positions, errors and other information as selected by the control file |
| | File with time tag in seconds of GPS week, X, Y, Z and Lat, Lon, HT, both in WGS 72 and the number of satellites used in the solution |
| | Optional file with time tag and Geometric Dilution of Precision (GDOP) every minute |

5. **Transducer positions.**

*a. Procedure*

The positions of the transducer were computed using an algorithm similar to the one used with the MR Falcon data. The only difference is that the GPS positions are three-dimensional, so the corrections for all dimensions were computed and applied.

The offsets between the transducer and the antenna and also the format of the input files were different. The program uses the same control file as the program CVFICA in order to compute the date time tag of each position.

*b. Program information*

| | |
|---|---|
| Program: | TRANSDUC GPS |
| Input: | File with time tag in seconds and WGS 72 coordinates |
| | Control file with the title and starting date of GPS week |
| Output: | File with date, time tag, latitude, longitude and ellipsoid height |
| | Optional listing with above information |
| Source: | See Appendix F |

### 6. Plots

It is possible to plot the track of the ship using either the GESAR solutions or the transducer positions as described before in Section C.5. Track plotting was done in order to give the GPS data coverage and data status. The program to plot is the same one used to plot the positions computed from the MR Falcon data but with the appropriate title (Figure 3.4).

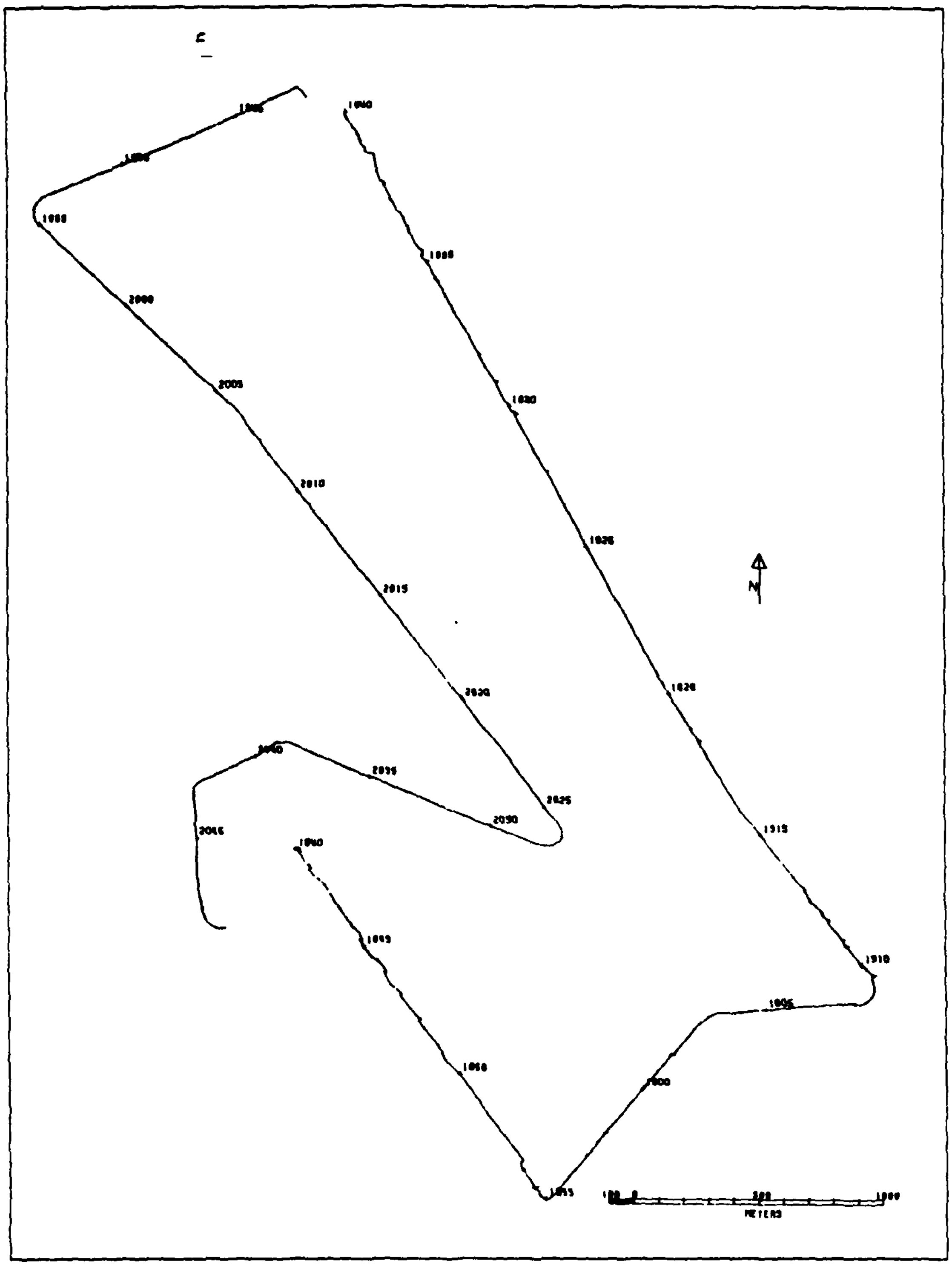


Figure 3.4 Plot of ship's track using TI-4100 data.

# IV. DATA ANALYSIS

## A. COMPUTATION OF DIFFERENCES

### 1. Approach

To find the accuracy of the GPS positions in a two-dimensional coordinate system, the observed positions in WGS 72 coordinates are transformed to UTM coordinates and compared with the UTM coordinates of the corresponding MR Falcon positions interpolated for the same time tag. The differences in the coordinates of Mini-Ranger and GPS positions are expressed in meters.

Due to the low sampling rate of the existing course data, only data from steady, straight courses were used for analysis. The data were divided into eleven periods of constant headings, while the data collected during the turns of the ship were deleted. This procedure made it possible to analyze the differences between GPS and Mini-Ranger data during the different courses.

Due to unexpected small differences found for positions computed using data from three satellites, several tests were made using various combinations of solutions. Although for data analysis many combinations were studied, three representative cases are discussed.

Different starting times during processing of the GPS data using the KALMN2 program were used in order to see the effects of the propagation of errors due to the initial noisy data, but the discrepancies were inconsistent. The term "noisy data" is used to refer to the oscillatory behavior resulting from the Kalman filter when the number of satellites changes from three to four or vice versa. The effect of ship's motion on the transfer of antenna positions to two chosen common points, i.e. the acoustic transducer and the GPS antenna, was found to be 0.2 m, which falls within the accuracy limits of GPS and hence is considered negligible for this study.

### 2. Case studies

The following cases were analyzed:

Case A : Data from four satellites were used or data from only three available satellites and geoidal height constraint for position computation were used.

Case B : Same as case A but using the geoidal height constraint when both three or four satellites were used.

Case C : Same as B but not using data from SV11.

3. **Differences obtained**

*a. Period 1. 19:14 to 19:20 (Cases A and B)*

TABLE 1

PERIOD 1, CASES A AND B.
DIFFERENCES BETWEEN GPS AND MINI-RANGER POSITIONS

| pos | Svs | Avg A | Avg B | Ranges(m) Min-Max A | Ranges(m) Min-Max B | |
|---|---|---|---|---|---|---|
| 179 | 6,8,11 | 26 | 26 | 24-32 | 24-32 | |
| 80 | 6,8,9,11 | 24 | 30 | 21-31 | 29-31 | |
| 1 | 6,8,11 | 27 | 30 | 27-27 | 30-30 | * |
| 1 | 6,8,9,11 | 34 | 42 | 34-34 | 42-42 | * |
| 1 | 6,8,11 | 34 | 42 | 34-34 | 42-42 | * |
| 23 | 6,8,9,11 | 27 | 31 | 25-29 | 30-33 | |
| 1 | 6,8,11 | 28 | 31 | 28-28 | 31-31 | * |
| 74 | 6,8,9,11 | 23 | 30 | 20-30 | 28-32 | |

* noisy data

Case A - using four satellites, or
four satellites with geoidal height constraint
Case B - geoidal height constraint in case A

pos - number of consecutive positions computed every second

During the first part of this period, all positions were computed using data from three satellites. In both cases (Table 1) the differences found are in the same range, 24 to 32 m. For the next 80 positions, computed using data from four satellites, Case A lead to values lower than in Case B. The upper limit of the ranges in cases, 31 m, is due to the initial oscillation from the Kalman filter.

The next part of the period is one of noisy data, i.e. changes from four satellites to three and vice-versa. In both cases the positional accuracy is degraded, giving larger differences between GPS and Mini-Ranger positions.

At the end of the period, with continuous data from four satellites and with the exception of one position, the differences are low, reaching 20 m in Case A and 28 m in Case B.

It was found that the use of geoidal height as a constraint for position computations with data from four satellites degrades the computed position. The reason for this is explained in Section 4.B. Noisy data causes oscillations in the observed differences which are due to the Kalman filter.

TABLE 2

SATELLITE VISIBILITY
16 AUGUST 1986

| Time | SV6 El | SV6 Az | SV8 El | SV8 Az | SV9 El | SV9 Az | SV11 El | SV11 Az | SV13 El | SV13 Az |
|---|---|---|---|---|---|---|---|---|---|---|
| 19:00 | 59 | 2 | 51 | 55 | 24 | 315 | 57 | 156 | -- | -- |
| 19:20 | 63 | 21 | 44 | 44 | 32 | 321 | 67 | 147 | 6 | 198 |
| 19:40 | 66 | 45 | 36 | 38 | 39 | 328 | 75 | 124 | 15 | 200 |
| 20:00 | 66 | 72 | 28 | 34 | 48 | 335 | 77 | 78 | 24 | 203 |
| 20:20 | 62 | 96 | 19 | 33 | 57 | 342 | 71 | 74 | 33 | 208 |
| 20:40 | 56 | 115 | 11 | 34 | 67 | 350 | 62 | 36 | 43 | 214 |

The offset of the GPS positions in relation to the MR Falcon positions is in a southeasterly direction (Figure 4.1 on page 40). Also the ship's course is close to the azimuth of SV9 (Table 2), which must be the reason for the successive tracking losses. The GPS antenna is in the shadow of the ship's mast when the satellite is low.

***b. Period 2. 19:20 to 19:25 (Cases A and B)***

All positions were computed using data from four satellites. There is a nine-second interruption of data in the beginning of the period corresponding to the time needed to change tapes in the receiver during logging.

In Case A the differences range from 17 to 26 m (Table 3). The maximum value was found in the first position after the lack of data. Most of the differences are around 19 m. In Case B the differences range from 23 to 38 m. The minimum value is found after the gap in data. Most of the differences are around 29 m. Visual comparison is possible by referring to Figures 4.2 and 4.3. As before the offset of the GPS positions is in the southeasterly direction.

TABLE 3

PERIOD 2, CASES A AND B.
DIFFERENCES BETWEEN GPS AND MINI-RANGER POSITIONS

| | | Ranges(m) Avg | | Min-Max | |
|---|---|---|---|---|---|
| pos | SVs | A | B | A | B |
| 295 | 6,8,9,11 | 19 | 29 | 17-26 | 23-38 |

Case A - using four satellites, or
four satellites with geoidal height constraint
Case B - geoidal height constraint in Case A

pos - number of consecutive positions computed every second

c. *Period 3. 19:25 to 19:30 ( Cases A and B )*

TABLE 4

PERIOD 3, CASES A AND B.
DIFFERENCES BETWEEN GPS AND MINI-RANGER POSITIONS

| | | Ranges(m) Avg | | Min-Max | | |
|---|---|---|---|---|---|---|
| pos | Svs | A | B | A | B | |
| 152 | 6,8,9,11 | 18 | 30 | 17-19 | 29-31 | |
| 1 | 6,8,11 | 18 | 32 | 18-18 | 32-32 | * |
| 1 | 6,8,9,11 | 13 | 28 | 13-13 | 28-28 | * |
| 9 | 6,8,11 | 30 | 31 | 17-37 | 28-33 | * |
| 118 | 6,8,9,11 | 26 | 33 | 24-37 | 32-36 | |
| 11 | 6,8,11 | 46 | 36 | 31-49 | 35-37 | * |
| 4 | 6,8,9,11 | 39 | 37 | 36-43 | 37-38 | * |
| 3 | 6,8,11 | 37 | 38 | 37-37 | 38-38 | * |

* noisy data

Case A - using four satellites, or
three satellites with geoidal height constraint
Case B - geoidal height constraint in Case A

pos - number of consecutive positions computed every second

This period is characterized by having noise in different parts of the data and shows great variation in the differences. In Case A, at the beginning of the period

the average differences are 18 m, after the first period of noisy data they reach values of 26 m, and at the end of the period the differences are up to 46 m. In Case B at the begining of the period the average differences are 30 m. This values changes to 33 m after the noisy data, and at end of the period the differences are up to 38 m. It is possible to distinguish the oscillation in the positions due to noisy data, much more emphasised in Case A than in Case B (Figures 4.4 and 4.5). The offset of the GPS positions is as before in the southeasterly direction.

The successive periods lacking data from one satellite are as before due to SV9, which is still in an azimuth close to the ship's course. The fact that use of geoidal height as a constraint with data from four satellites for computation of positions does not improve the solution is evident in Table 4.

*d. Period 4. 19:30 to 19:35 (Cases A and B)*

TABLE 5

PERIOD 4, CASES A AND B.
DIFFERENCES BETWEEN GPS AND MINI-RANGER POSITIONS

| pos | SVs | Avg A | Avg B | Ranges(m) Min-Max A | Ranges(m) Min-Max B | |
|---|---|---|---|---|---|---|
| 7 | 6,8,11 | 38 | 38 | 38-40 | 38-39 | |
| 40 | 6,8,9,11 | 31 | 35 | 29-40 | 34-39 | |
| 7 | 6,8,11 | 41 | 38 | 32-43 | 37-39 | * |
| 1 | 6,8,9,11 | 38 | 37 | 38-38 | 37-37 | * |
| 1 | 6,8,11 | 38 | 38 | 38-38 | 38-38 | * |
| 49 | 6,8,9,11 | 30 | 35 | 27-38 | 33-39 | |
| 10 | 6,8,11 | 40 | 37 | 31-44 | 35-38 | * |
| 130 | 6,8,9,11 | 31 | 38 | 28-41 | 37-40 | |
| 1 | 6,8,11 | 34 | 38 | 34-34 | 38-38 | * |
| 11 | 6,8,9,11 | 33 | 39 | 29-38 | 36-45 | * |
| 9 | 6,8,11 | 41 | 38 | 33-46 | 36-40 | * |
| 2 | 6,8,9,11 | 39 | 37 | 38-40 | 37-38 | * |
| 1 | 6,8,11 | 38 | 38 | 38-38 | 38-38 | * |
| 81 | 6,8,9,11 | 38 | 41 | 35-44 | 40-45 | |

* noisy data

Case A - using four satellites, or
three satellites with geoidal height constraint
Case B - geoidal height constraint in Case A

pos - number of consecutive positions computed every second

This period is characterized by successive changes in the number of satellites used in the computation of positions; the differences are larger than observed in the previous periods.Successive losses of lock on SV9 were the cause for this. In Case A (Figure 4.6) it is possible to see the oscillations of the computed positions when the data are noisy. Improvement in the solutions is seen (Table 5) when we change from three to four satellites; the average differences go from 41 m to 30 m, becoming higher values when only three satellites are available.

In Case B the differences have higher values than in Case A, but the ranges are smaller due to the smaller, noisy oscillations. As before the noisy is caused by the loss of lock on SV9, and the offset in the GPS positions is in the southeasterly direction from the Mini-Ranger positions.

***e. Period 5. 19:35 to 1940 (Cases A and B)***

This period has the noisiest data processed, so the differences have greater spread. Although the range between differences is wide, 20 to 68 m in Case A and 29 to 67 m in Case B, the differences are mostly smaller in Case A than in Case B.

In Figure 4.7 we see successive jumps from three satellites to four and vice versa. The GPS positions are south and east of the Mini-Ranger positions. The differences in the northings are almost double of the ones observed in the eastings. The reason for the frequent changes in the number of satellites used is the relatively low altitude of SV9 and an azimuth close to ship's heading, which together with the pitch and roll led frequently to shadowing of the TI-4100 antenna.

***f. Period 6. 19:47 to 19:53 (Cases A, B and C)***

This period is characterized also by noisy data, but it is for a different reason. Here data from SV8 is rejected during the phase of smoothing it with Doppler data. The observed roll is higher than in previous periods, caused perhaps by the almost 90° change in course. As Table 2 shows, SV8 is setting, having a lower elevation than any other satellite used during this period.

There are no significant differences between Cases A and B, and average differences range from 26 to 30 m. In Case C we see that even lowering the number of satellites to two or three and using the geoidal height as a constraint, smaller differences are obtained than the ones computed with data from SV11 (Table 6). The offset in the positions has no relation to the course of the ship, i.e. it is still in the southeasterly direction, and a small or no time lag exists between the data of the two systems (Figure 4.8).

## TABLE 6

### PERIOD 6, CASES A, B AND C. DIFFERENCES BETWEEN GPS AND MINI-RANGER POSITIONS

| | | Ranges(m) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Avg | | | Min-Max | | | |
| pos | SVs | A | B | C | A | B | C | |
| 16 | 8,9,11,13 | 28 | 29 | 29 | 28-29 | 28-30 | 28-30 | |
| 1 | 9,11,13 | 27 | 29 | 28 | 27-27 | 29-29 | 28-28 | * |
| 3 | 8,9,11,13 | 28 | 29 | 28 | 28-29 | 29-30 | 28-29 | * |
| 1 | 9,11,13 | 27 | 28 | 26 | 27-27 | 28-28 | 26-26 | * |
| 4 | 8,9,11,13 | 28 | 28 | 26 | 27-28 | 27-30 | 25-27 | * |
| 1 | 9,11,13 | 28 | 28 | 26 | 28-28 | 28-28 | 26-26 | * |
| 79 | 8,9,11,13 | 27 | 28 | 26 | 26-29 | 26-30 | 24-28 | |
| 1 | 9,11,13 | 27 | 28 | 26 | 27-27 | 28-28 | 26-26 | * |
| 35 | 8,9,11,13 | 29 | 30 | 30 | 27-32 | 28-33 | 27-33 | |
| 1 | 9,11,13 | 28 | 29 | 28 | 28-28 | 29-29 | 28-28 | * |
| 17 | 8,9,11,13 | 29 | 29 | 29 | 28-30 | 28-30 | 27-30 | |
| 1 | 9,11,13 | 28 | 29 | 27 | 28-28 | 29-29 | 27-27 | * |
| 20 | 8,9,11,13 | 29 | 29 | 28 | 28-31 | 28-31 | 26-32 | |
| 1 | 9,11,13 | 28 | 29 | 27 | 28-28 | 29-29 | 27-27 | * |
| 162 | 8,9,11,13 | 28 | 29 | 27 | 26-31 | 27-31 | 24-31 | |
| 1 | 9,11,13 | 28 | 30 | 27 | 28-28 | 30-30 | 27-27 | * |
| 1 | 8,9,11,13 | 29 | 30 | 28 | 29-29 | 30-30 | 28-28 | * |
| 1 | 9,11,13 | 27 | 29 | 27 | 27-27 | 29-29 | 27-27 | * |
| 1 | 8,9,11,13 | 29 | 30 | 28 | 29-29 | 30-30 | 28-28 | * |
| 1 | 9,11,13 | 27 | 28 | 25 | 27-27 | 28-28 | 25-25 | * |
| 5 | 8,9,11,13 | 27 | 27 | 21 | 26-27 | 26-27 | 20-23 | * |
| 1 | 9,11,13 | 27 | 28 | 24 | 27-27 | 28-28 | 24-24 | * |
| 2 | 8,9,11,13 | 29 | 30 | 27 | 29-30 | 29-31 | 20-21 | * |
| 1 | 9,11,13 | 26 | 27 | 23 | 26-26 | 27-27 | 23-23 | * |
| 6 | 8,9,11,13 | 26 | 26 | 21 | 26-28 | 25-28 | 20-24 | |

* noisy data

Case A - using four satellites, or three satellites with geoidal height constraint
Case B - geoidal height constraint in Case A
Case C - ignoring SV11 but constraining with geoidal height
pos - number of consecutive positions computed every second

g. ***Period 7. 19:57 to 20:05 (Cases A, B and C)***

In Case B there is an improvement in the positions in relation to Case A. If we refer to previous periods, we see that what is happening is the reverse of what was happening there, i.e. the use of the geoidal height in positions computed using data from four satellites improves the solution. As before, we see that noisy data causes an oscillation in the observed differences but with small amplitudes. Noteworthy are the highly improved positions indicated by a 13-m difference (Table 7).

TABLE 7

PERIOD 7, CASES A, B AND C
DIFFERENCES BETWEEN GPS AND MINI-RANGER POSITIONS

| pos | SVs | Avg A | Avg B | Avg C | Ranges(m) Min-Max A | B | C | |
|---|---|---|---|---|---|---|---|---|
| 185 | 8,9,11,13 | 25 | 23 | 21 | 20-27 | 19-25 | 17-23 | |
| 1 | 8,11,13 | 24 | 23 | 20 | 24-24 | 23-23 | 20-20 | * |
| 22 | 8,9,11,13 | 22 | 20 | 18 | 20-24 | 18-22 | 16-20 | |
| 1 | 8,11,13 | 22 | 21 | 18 | 22-22 | 21-21 | 18-18 | * |
| 17 | 8,9,11,13 | 22 | 21 | 18 | 20-25 | 19-23 | 17-21 | |
| 1 | 8,11,13 | 23 | 22 | 19 | 23-23 | 22-22 | 19-19 | * |
| 12 | 8,9,11,13 | 22 | 20 | 17 | 21-22 | 19-21 | 17-21 | |
| 1 | 8,11,13 | 19 | 19 | 16 | 19-19 | 19-19 | 16-16 | * |
| 72 | 8,9,11,13 | 20 | 18 | 16 | 18-22 | 17-19 | 13-18 | |
| 1 | 8,11,13 | 19 | 19 | 16 | 19-19 | 19-19 | 16-16 | * |
| 13 | 8,9,11,13 | 19 | 18 | 14 | 17-20 | 17-19 | 13-16 | |
| 1 | 8,11,13 | 18 | 17 | 14 | 18-18 | 17-17 | 14-14 | * |
| 81 | 8,9,11,13 | 21 | 19 | 16 | 19-26 | 17-24 | 14-21 | |
| 1 | 9,11,13 | 17 | 17 | 14 | 17-17 | 17-17 | 14-14 | * |
| 35 | 8,9,11,13 | 20 | 18 | 16 | 19-22 | 16-20 | 13-18 | |
| 1 | 9,11,13 | 17 | 16 | 13 | 17-17 | 16-16 | 13-13 | * |
| 2 | 8,9,11,13 | 29 | 25 | 23 | 28-29 | 25-26 | 22-23 | * |
| 1 | 9,11,13 | 27 | 24 | 21 | 27-27 | 24-24 | 21-21 | * |
| 27 | 8,9,11,13 | 25 | 23 | 21 | 18-36 | 17-34 | 15-31 | |

* noisy data

Case A - using four satellites, or
three satellites with geoidal height constraint
Case B - geoidal height constraint in Case A
Case C - ignoring SV11 but constraining
with geoidal height
pos - number of consecutive positions computed every second

The GPS positions are also south and east of the MR Falcon positions, but the fact of ignoring SV11 causes a decrease in the differences in easting (Figure 4.8).

***h. Period 8. 20:07 to 20:13 (Cases A, B and C)***

During this period all differences in all cases are smaller than 21 m (Table 8). The higher values are obtained after the computation of a position using fewer than four satellites in Cases A and B, and three satellites in Case C, and are due to the oscillation caused by the Kalman filter. Table 8 shows that constraining the positions computed using data from four satellites improves the solution; the minimum difference reaches only 10 m. Also, ignoring SV11 causes a reduction of the differences, mainly in the easting, and we see that the differences are smaller than in the other cases (Table 8). Figures 4.10 and 4.11 show the improvement in the positions when SV11 is ignored.

TABLE 8

PERIOD 8, CASES A, B AND C.
DIFFERENCES BETWEEN GPS AND MINI-RANGER POSITIONS

| | | Ranges(m) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Avg | | | Min-Max | | |
| pos | SVs | A | B | C | A | B | C | |
| 37 | 8,9,11,13 | 19 | 19 | 14 | 19-21 | 16-18 | 13-15 | |
| 1 | 8,11,13 | 18 | 17 | 14 | 18-18 | 17-17 | 14-14 | * |
| 153 | 8,9,11,13 | 20 | 17 | 15 | 17-21 | 16-19 | 12-17 | |
| 1 | 8,11,13 | 17 | 17 | 13 | 17-17 | 17-17 | 13-13 | * |
| 28 | 8,9,11,13 | 20 | 17 | 15 | 19-21 | 16-19 | 13-16 | |
| 1 | 8,11,13 | 17 | 17 | 13 | 17-17 | 17-17 | 13-13 | * |
| 142 | 8,9,11,13 | 19 | 16 | 12 | 17-20 | 15-17 | 10-14 | |

* noisy data

Case A - using four satellites, or
three satellites with geoidal height constraint
Case B - geoidal height constraint in Case A
Case C - ignoring SV11 but constraining
with geoidal height
pos - number of consecutive positions computed every second

*i. Period 9. 20:13 to 20:20 (Cases A, B and C)*

TABLE 9

PERIOD 9, CASES A, B AND C.
DIFFERENCES BETWEEN GPS AND MINI-RANGER POSITIONS

| | | Ranges(m) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Avg | | | Min-Max | | |
| pos | SVs | A | B | C | A | B | C | |
| 391 | 8,9,11,13 | 20 | 17 | 13 | 19-22 | 15-18 | 11-14 | |
| 1 | no data | 18 | 15 | 11 | 18-18 | 15-15 | 11-11 | * |
| 31 | 8,9,11,13 | 20 | 15 | 11 | 18-21 | 15-16 | 10-11 | |

* noisy data

Case A - using four satellites, or
three satellites with geoidal height constraint
Case B - geoidal height constraint in Case A
Case C - ignoring SV11 but constraining
with geoidal height
pos - number of consecutive positions computed every second

The differences found during this period are similar to the ones obtained in period 8. Table 9 indicates that the differences in all cases are correlated as before. The oscillations are due to the noise in the data from the MR Falcon and not to the GPS positions, which define a smooth and continuous course (Figure 4.12).

*j. Period 10. 20:20 to 20:25 (Cases A, B and C)*

TABLE 10

PERIOD 10, CASES A, B AND C.
DIFFERENCES BETWEEN GPS AND MINI-RANGER POSITIONS

| | | Ranges(m) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Avg | | | Min-Max | | |
| pos | SVs | A | B | C | A | B | C |
| 9 | 8,9,11,13 | 20 | 16 | 11 | 19-21 | 14-16 | 9-11 |
| 88 | 8,9,13 | 11 | 11 | 11 | 10-17 | 10-15 | 10-12 |
| 206 | 6,8,9,13 | 25 | 25 | 24 | 15-26 | 15-26 | 15-26 |

Case A - using four satellites, or
three satellites with geoidal height constraint
Case B - geoidal height constraint in Case A
Case C - ignoring SV11 but constraining
with geoidal height
pos - number of consecutive positions computed every second

During the first tests, the differences were smaller when the positions where computed from three satellites, SV 11 excluded and the ship constrained to the geoidal height, than the ones using four satellites, SV11 or SV6 included. This happened because during data acquisition SV6 was selected to replace SV11, and while the receiver was not locked on the SV6, only data collected from three satellites was good (Figure 4.13).

In Case B (Figure 4.14 or Table 10) constraint of the position to the geoidal height improves the solution where SV11 is used. In Case C (Figure 4.15) we notice a reduction in the differences in the positions where data from SV11 was used. When SV6 replaces SV11, in all cases the differences are larger but of same approximate magnitude.

*k. Period 11. 20:30 to 20:37 (Cases A, B and C)*

TABLE 11

PERIOD 11, CASES A, B AND C.
DIFFERENCES BETWEEN GPS AND MINI-RANGER POSITIONS

| | | Ranges(m) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Avg | | | Min-Max | | |
| pos | SVs | A | B | C | A | B | C |
| 130 | 6,8,9,13 | 35 | 38 | 38 | 35-36 | 37-39 | 37-39 |
| 287 | 8,9,13 | 36 | 36 | 36 | 30-37 | 30-38 | 30-38 |

Case A - using four satellites, or
three satellites with geoidal height constraint
Case B - geoidal height constraint in Case A
Case C - ignoring SV11 but constraining
with geoidal height
pos - number of consecutive positions computed every second

The initial positions were computed using data from four satellites, and after 20h32m10.7s the receiver started to track SV12 in place of SV8, but no broadcast ephemeris data were received during this period. The differences computed using data from three satellites are the same in all cases, but those computed using data from four satellites have different values. Thus in Case A the differences are smaller than in Cases B and C, where the positions are constrained to the geoidal height (Table 11). In all cases the differences in eastings are larger than in northings, contrary to what was happening before; this offset is similar for the other two cases (Figure 4.16).

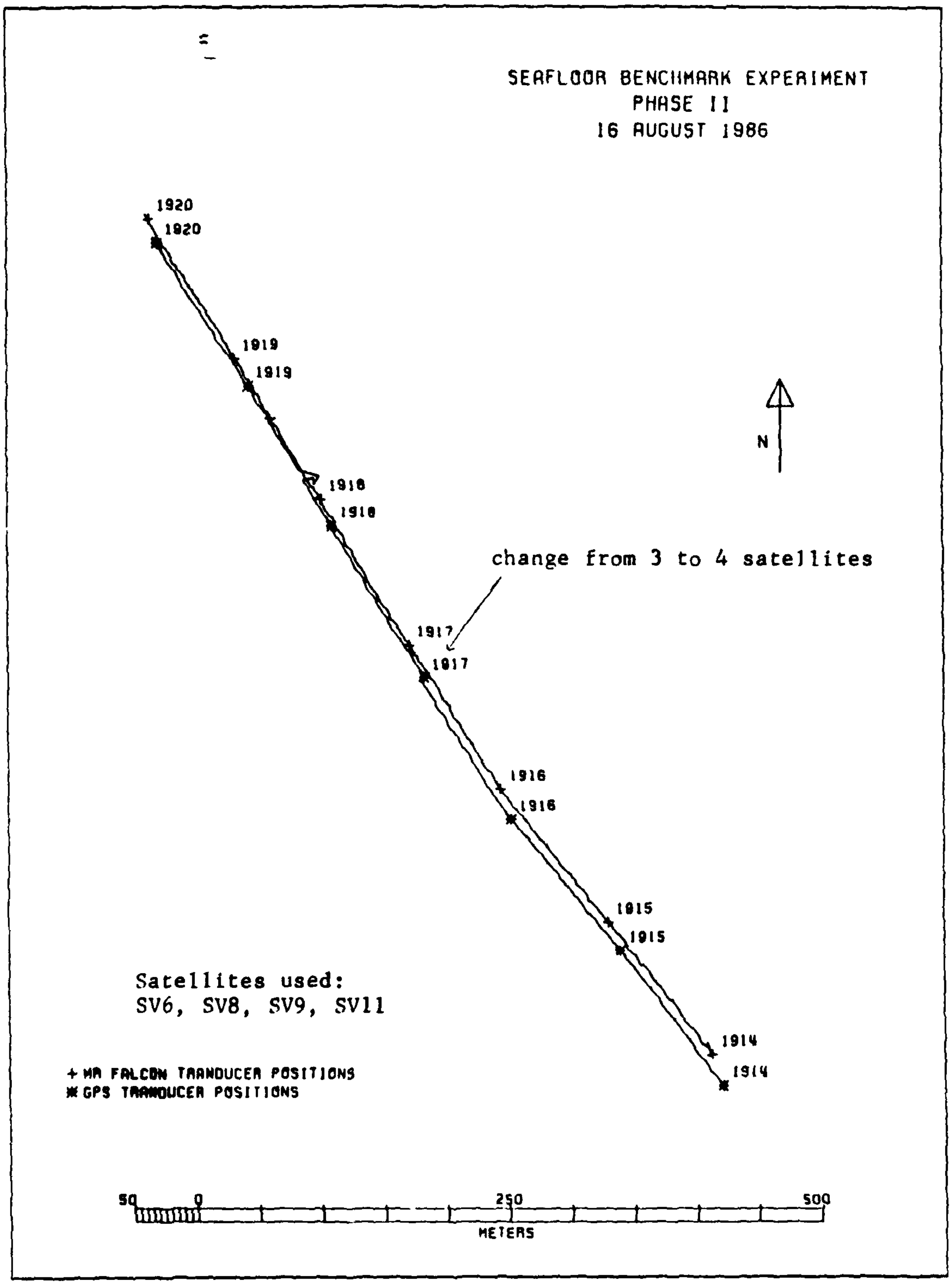



Figure 4.1 Period 1 (Case A). Using all available satellites.

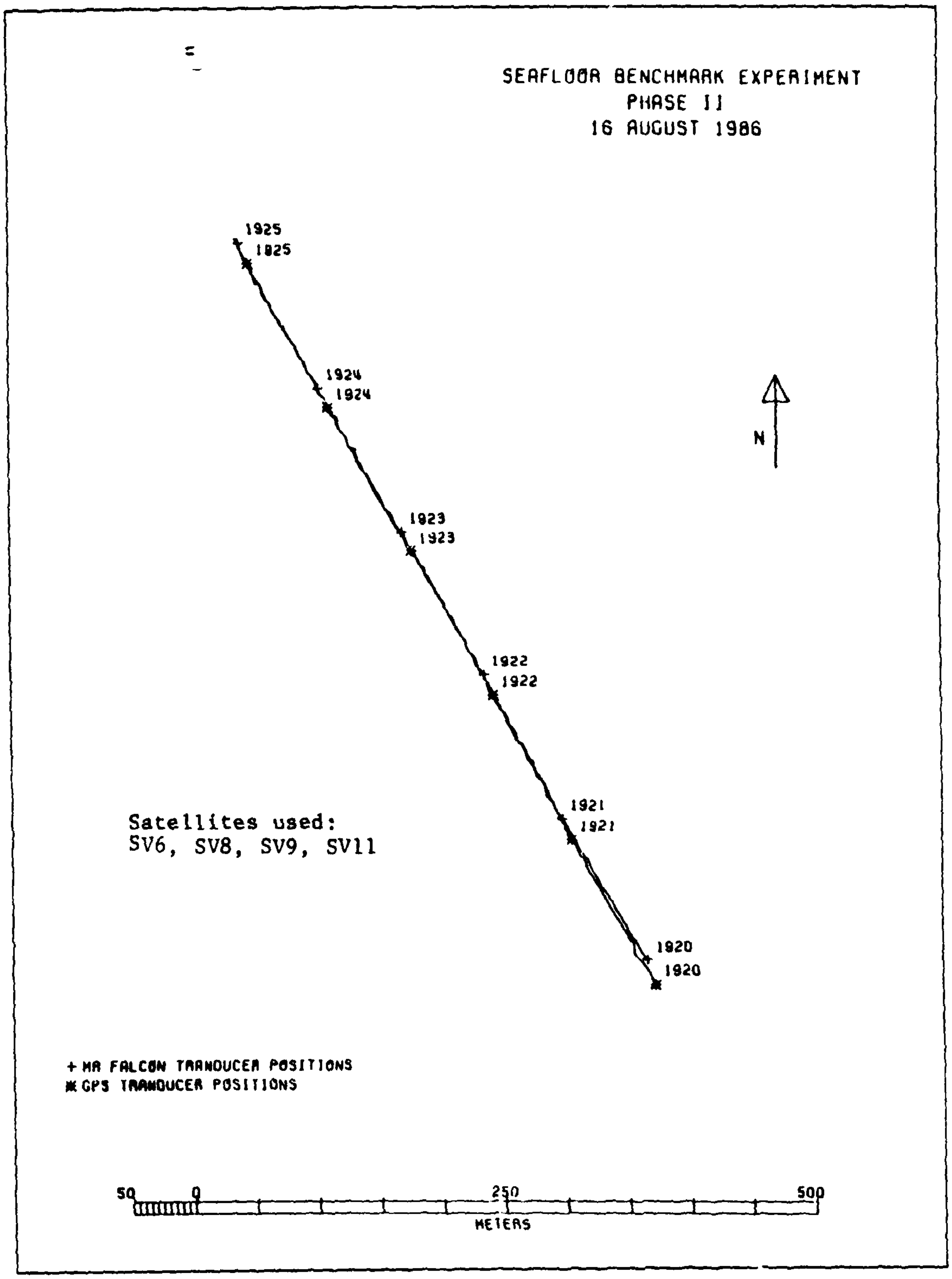



Figure 4.2 Period 2 (Case A). Using all available satellites.

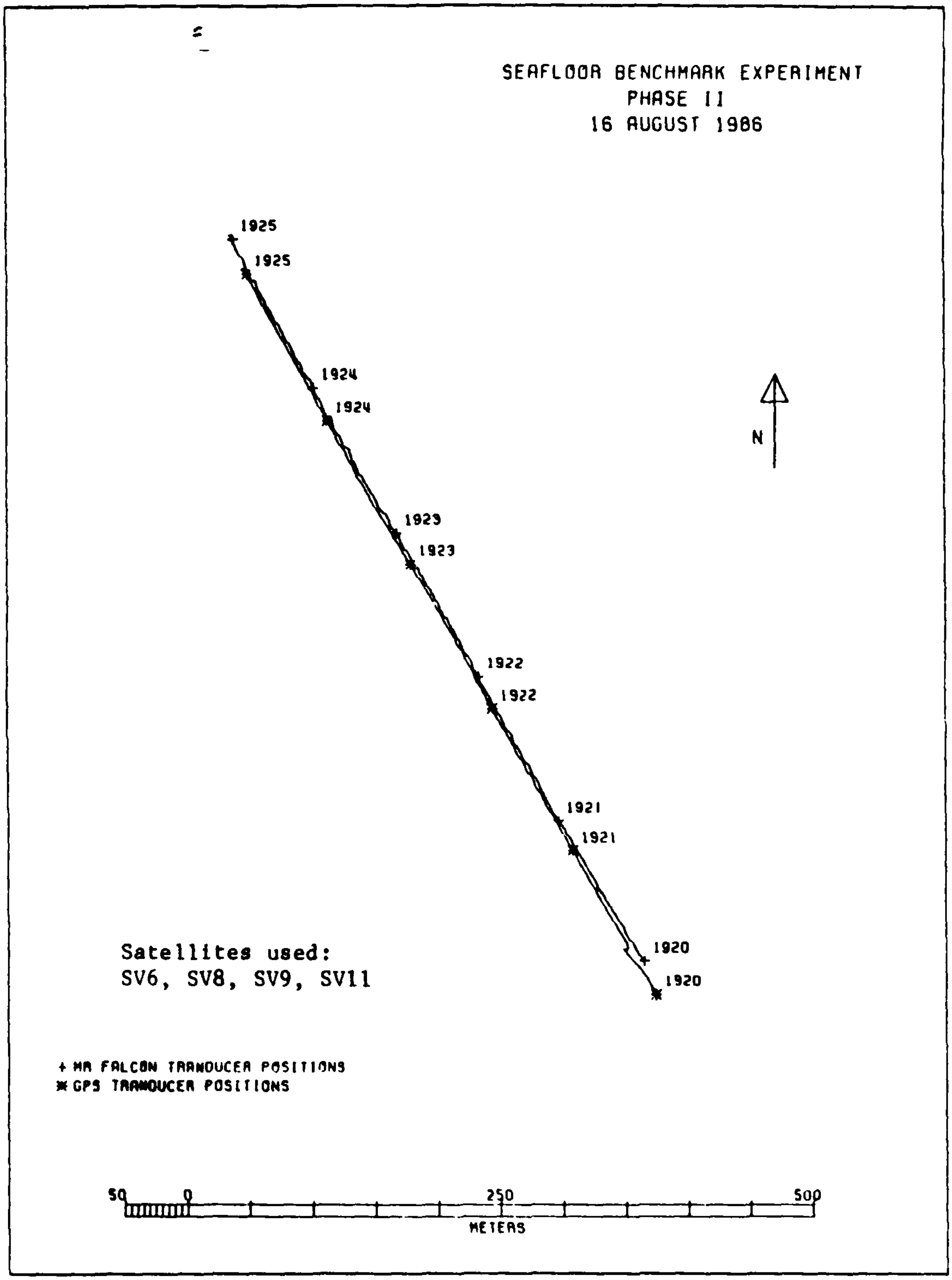



Figure 4.3 Period 2 (Case B). Constraining to geoidal height.

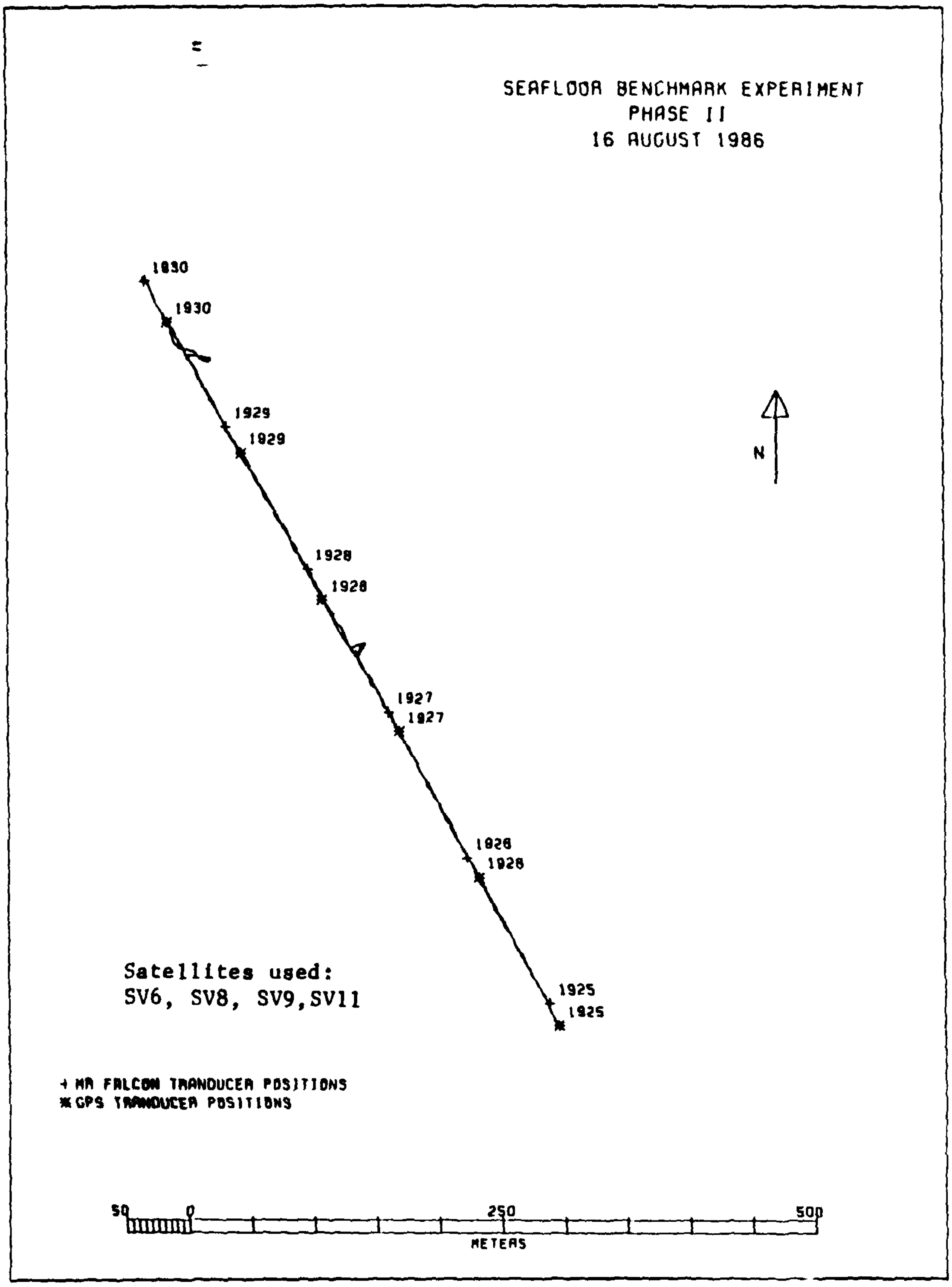



Figure 4.4 Period 3 (Case A). Using all available satellites.

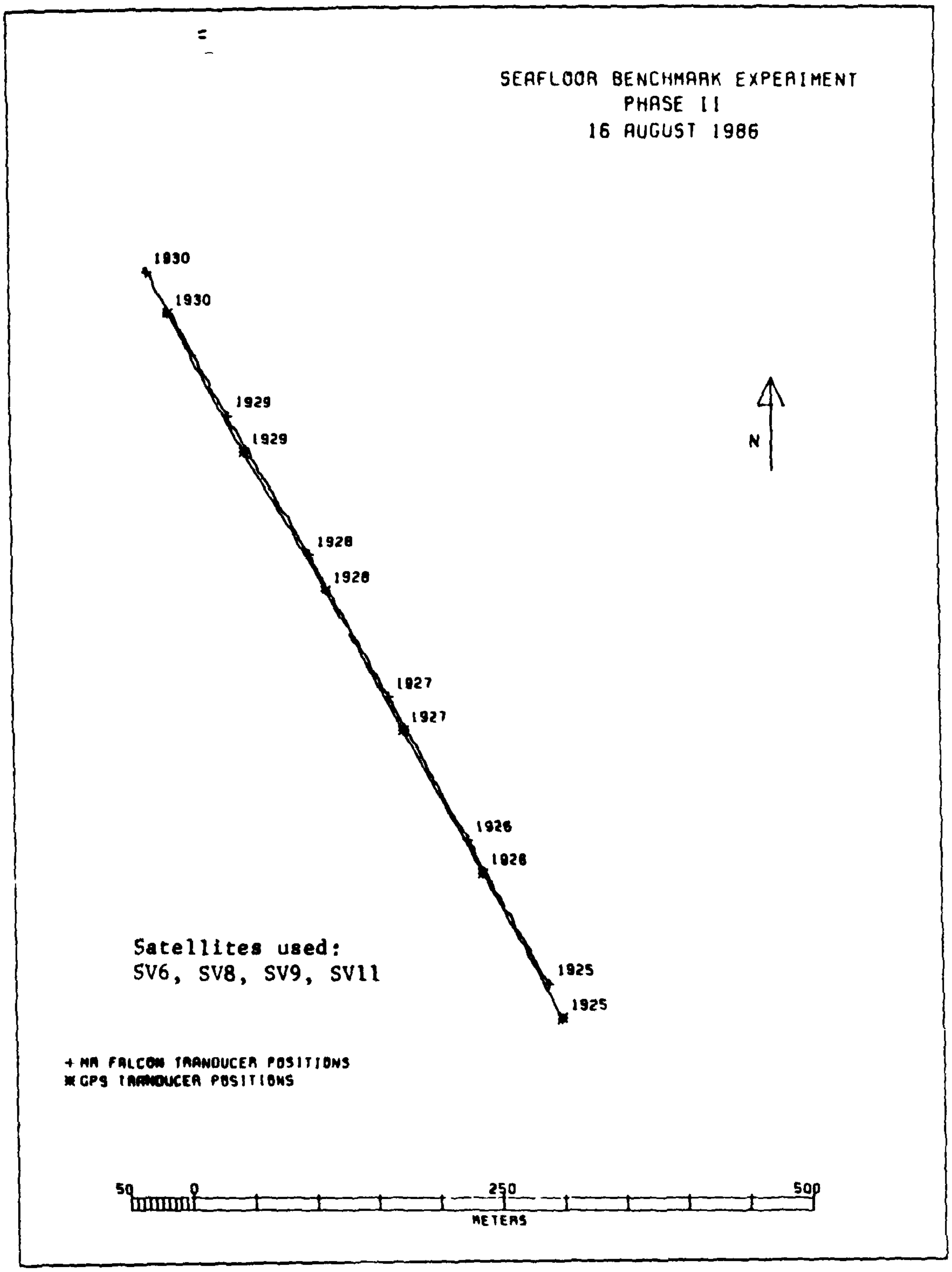



Figure 4.5 Period 3 (Case B). Constraining to geoidal height.

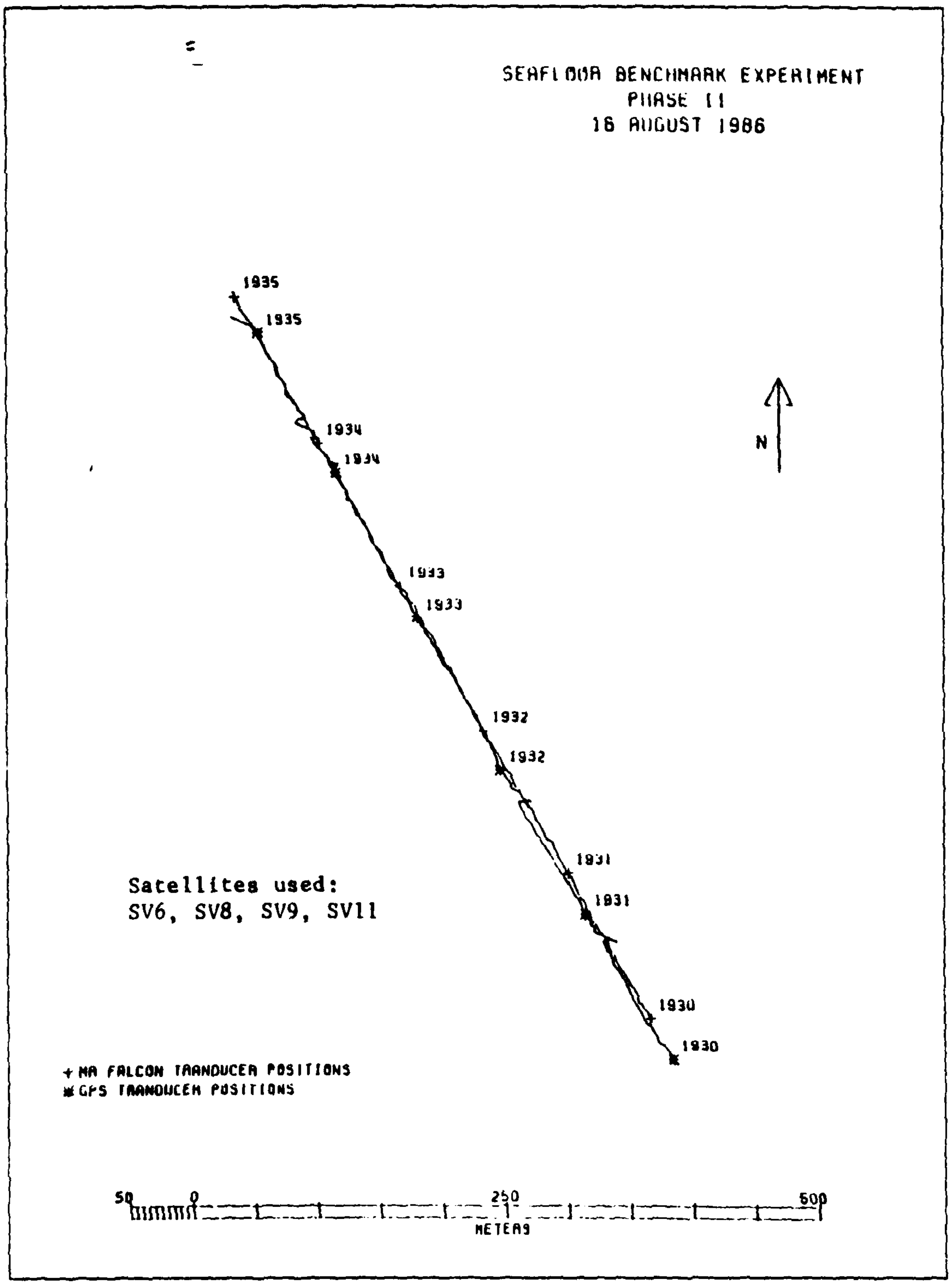



Figure 4.6 Period 4 (Case A). Using all available satellites.

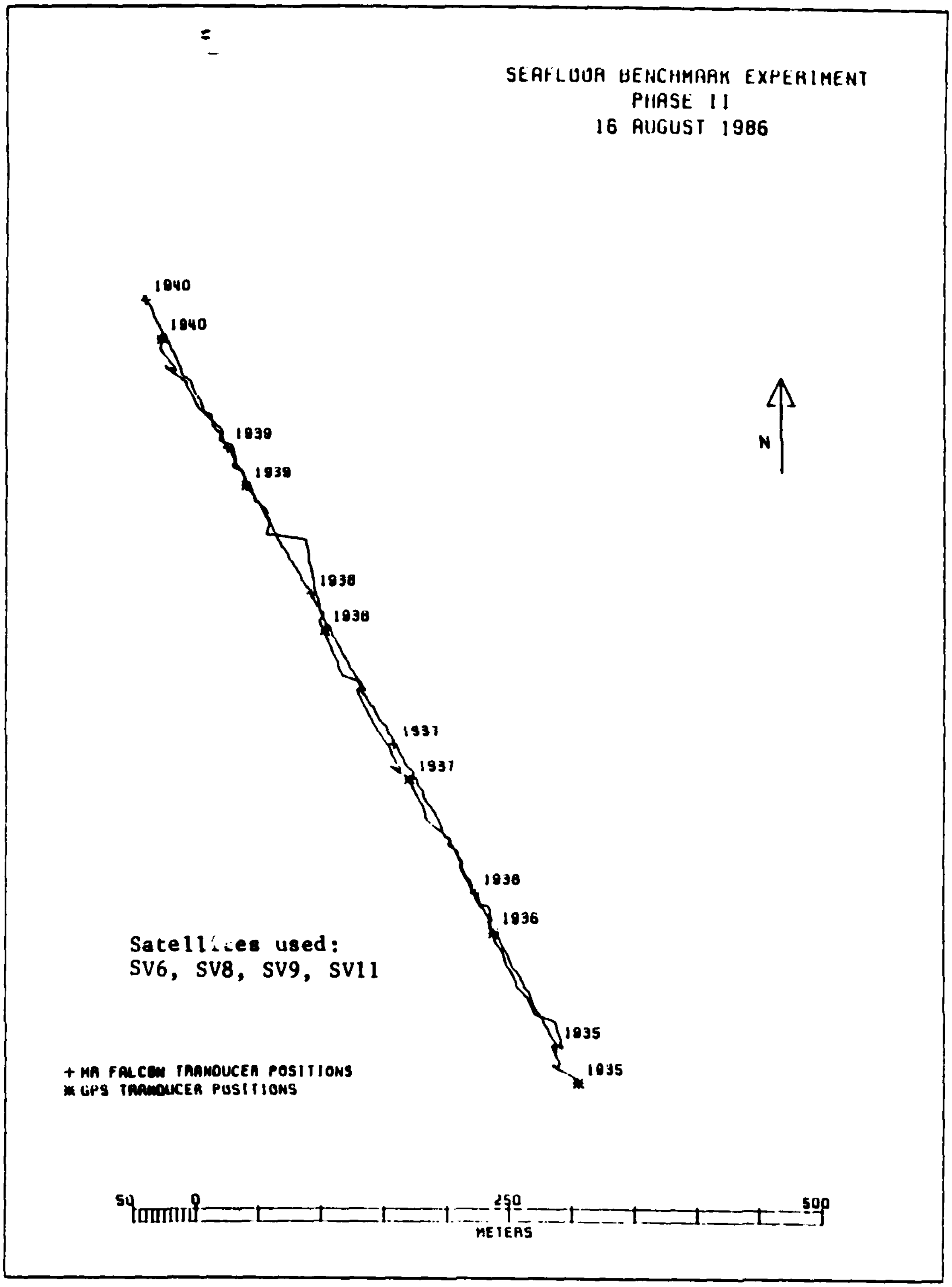



Figure 4.7 Period 5 (Case A). Using all available satellites.

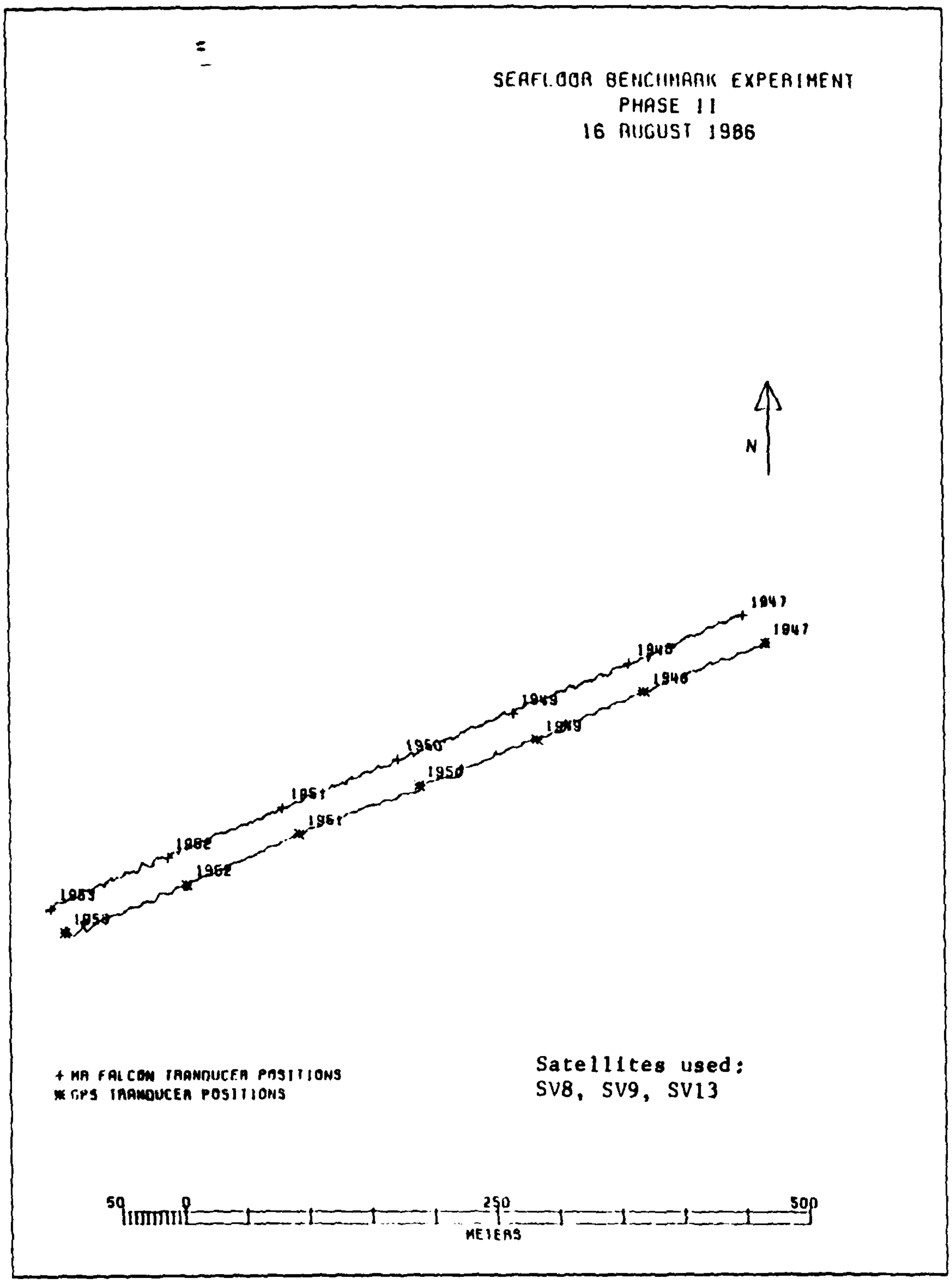



Figure 4.8 Period 6 (Case C). Ignoring SV11.

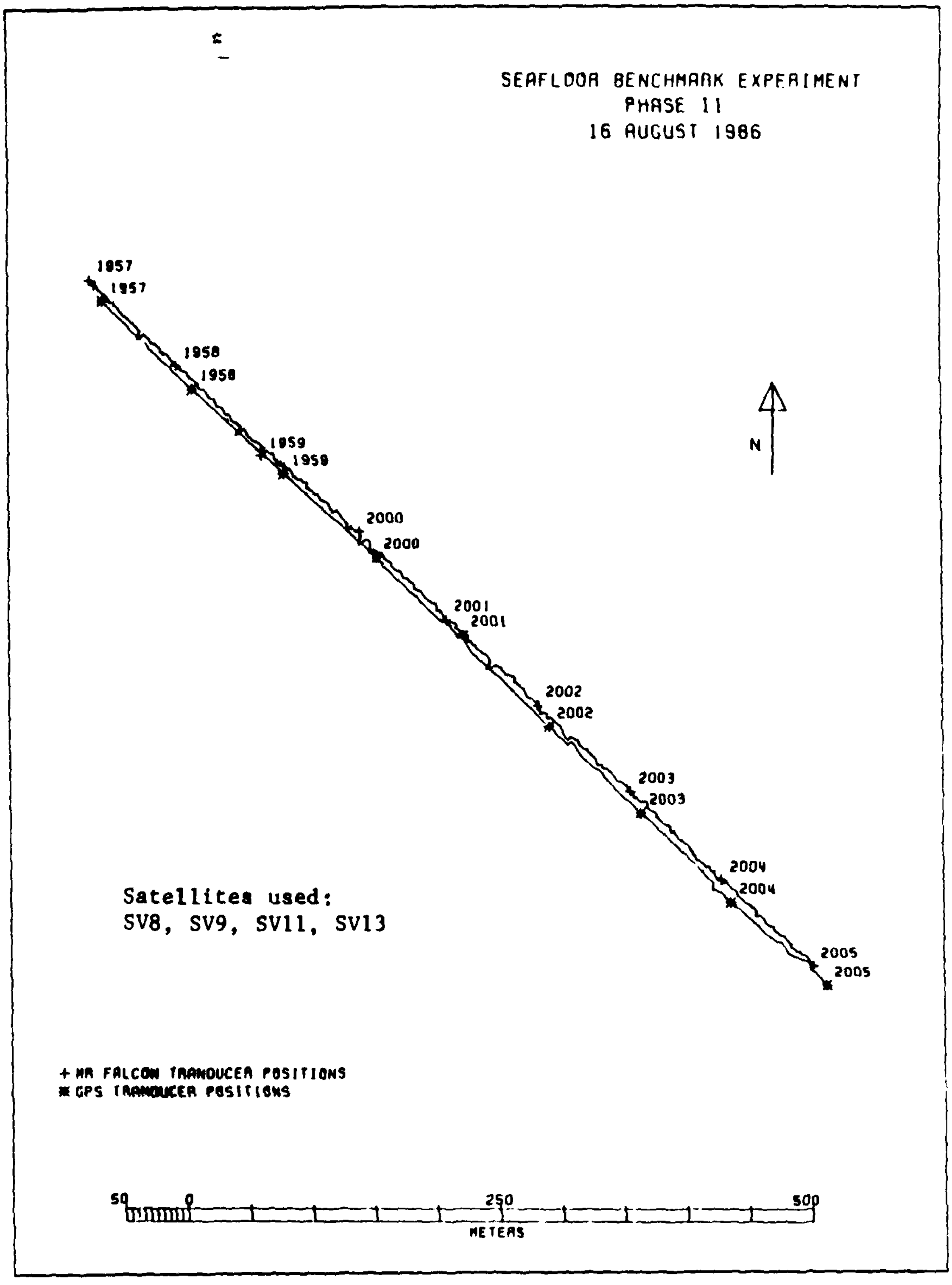



Figure 4.9 Period 7 (Case B). Constraining to geoidal height.

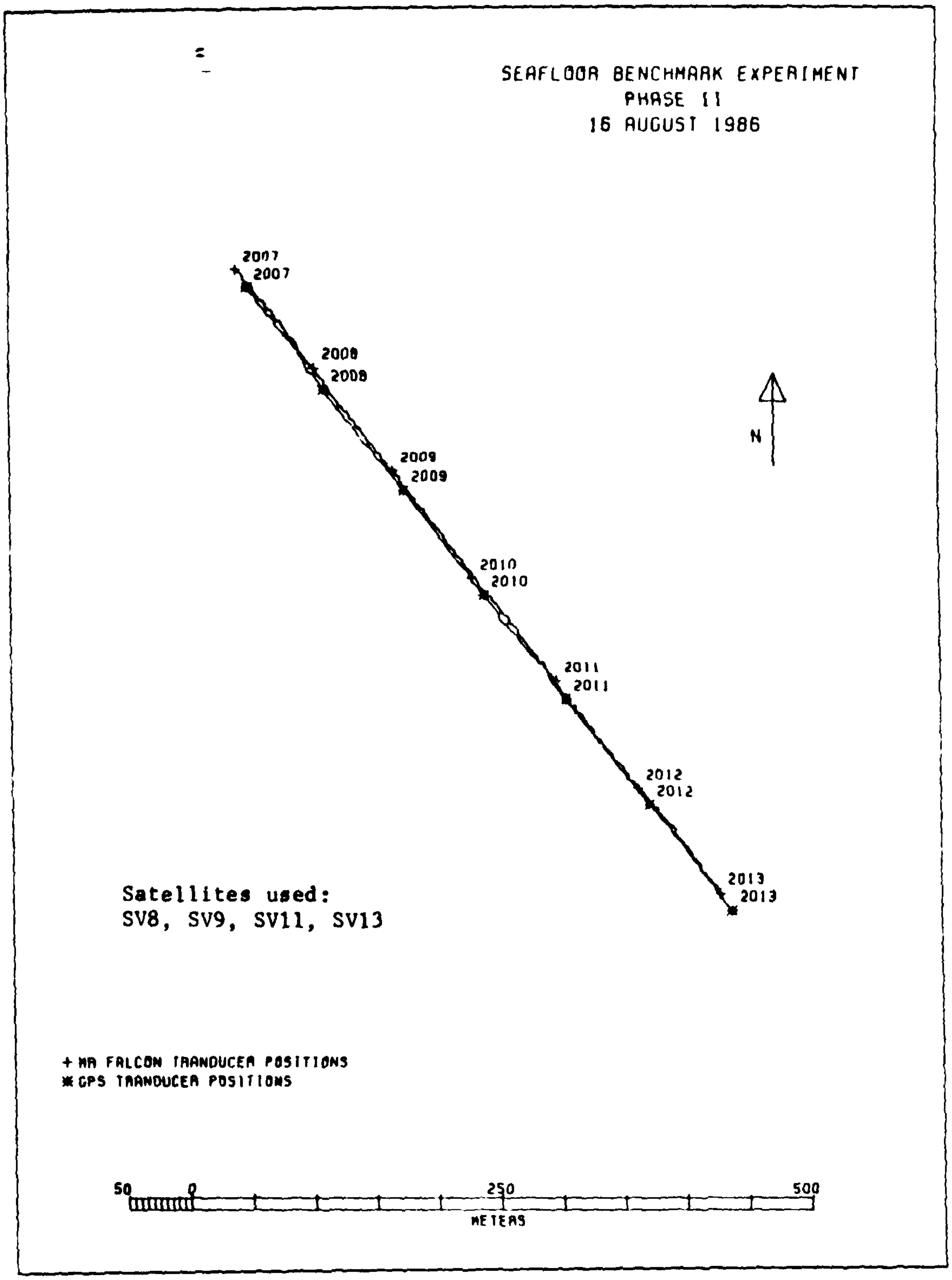



Figure 4.10 Period 8 (Case B). Constraining to geoidal height.

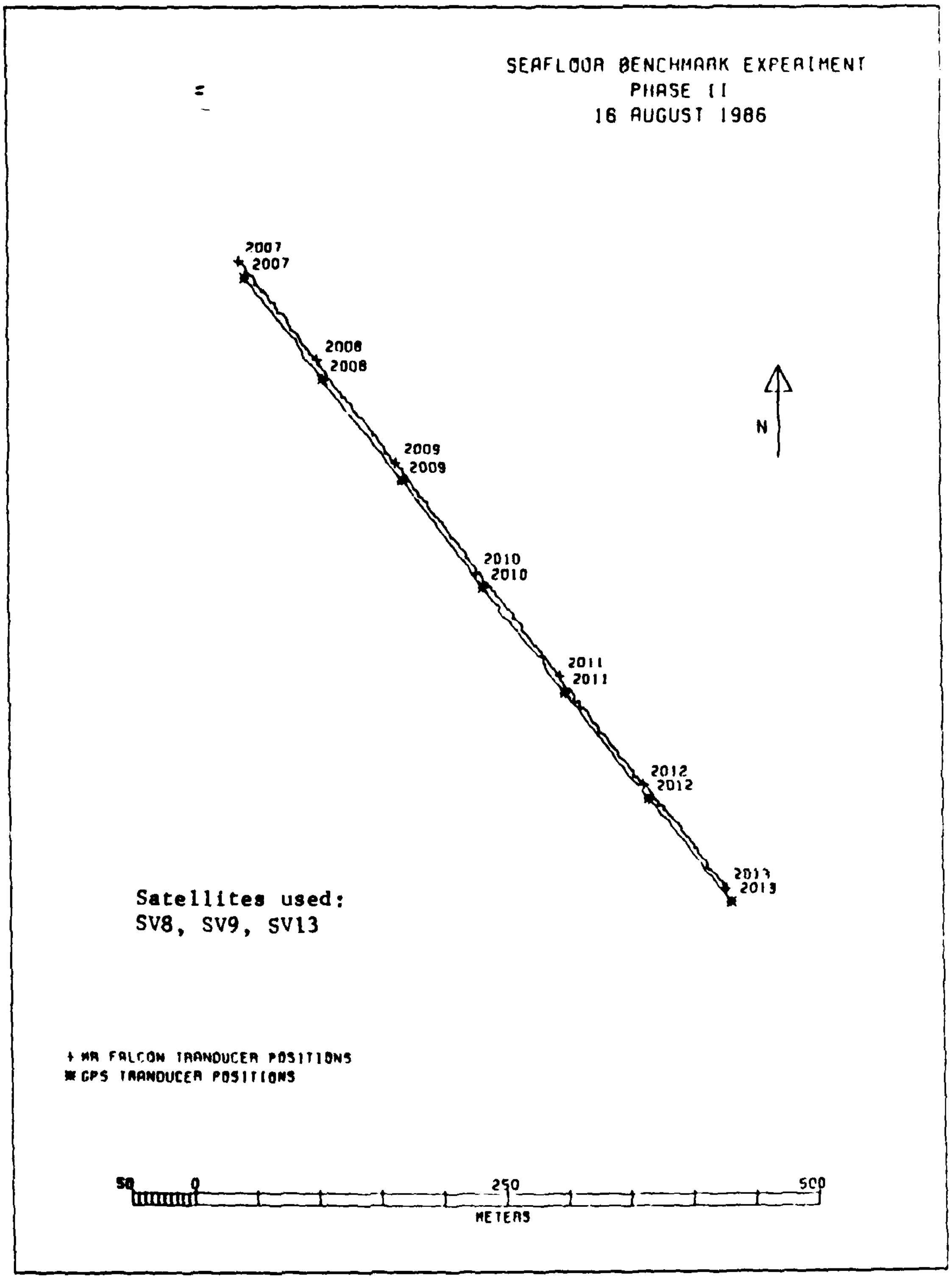



Figure 4.11 Period 8 (Case C). Ignoring SV11.

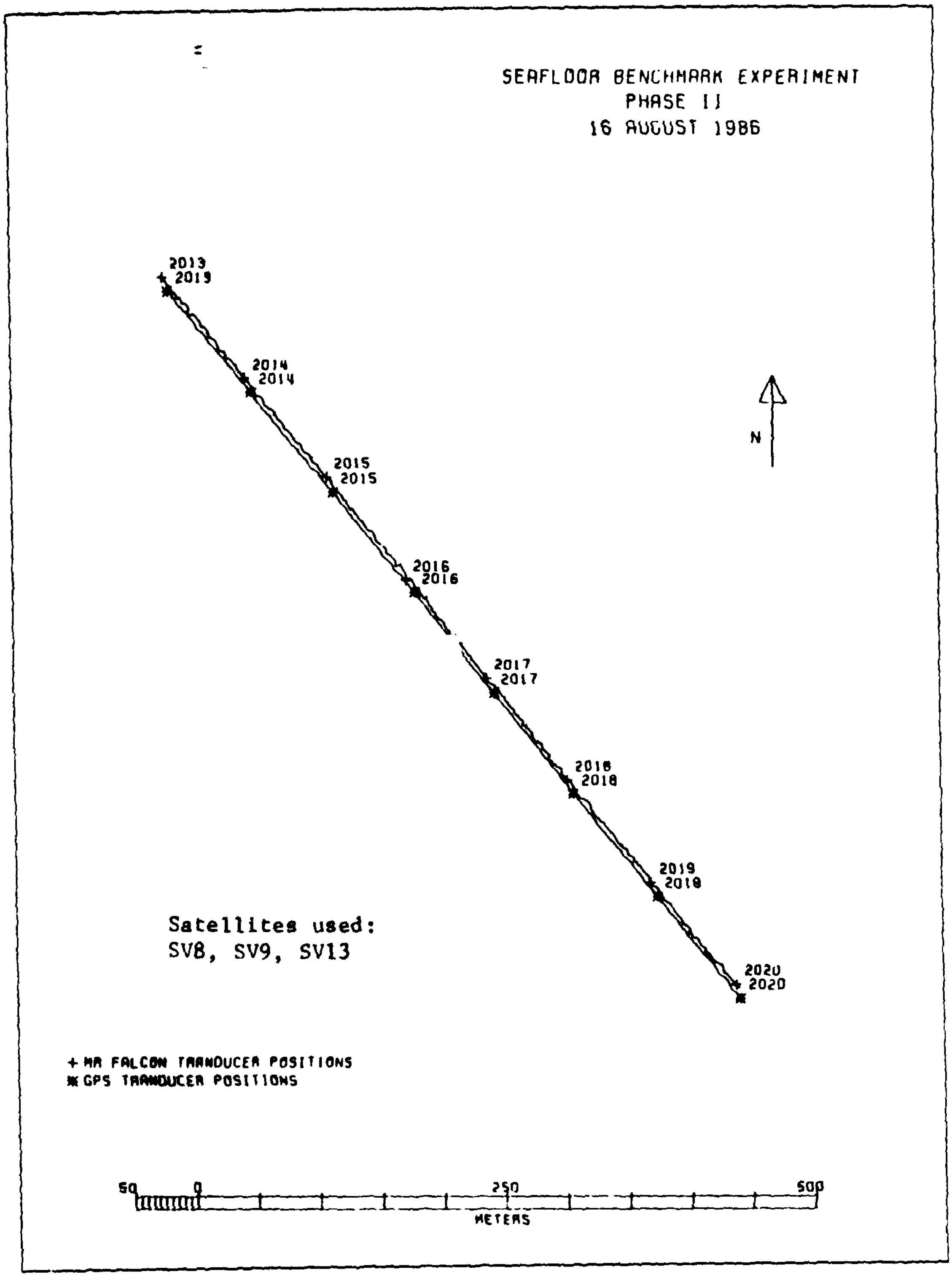



Figure 4.12 Period 9 (Case C). Ignoring SV11.

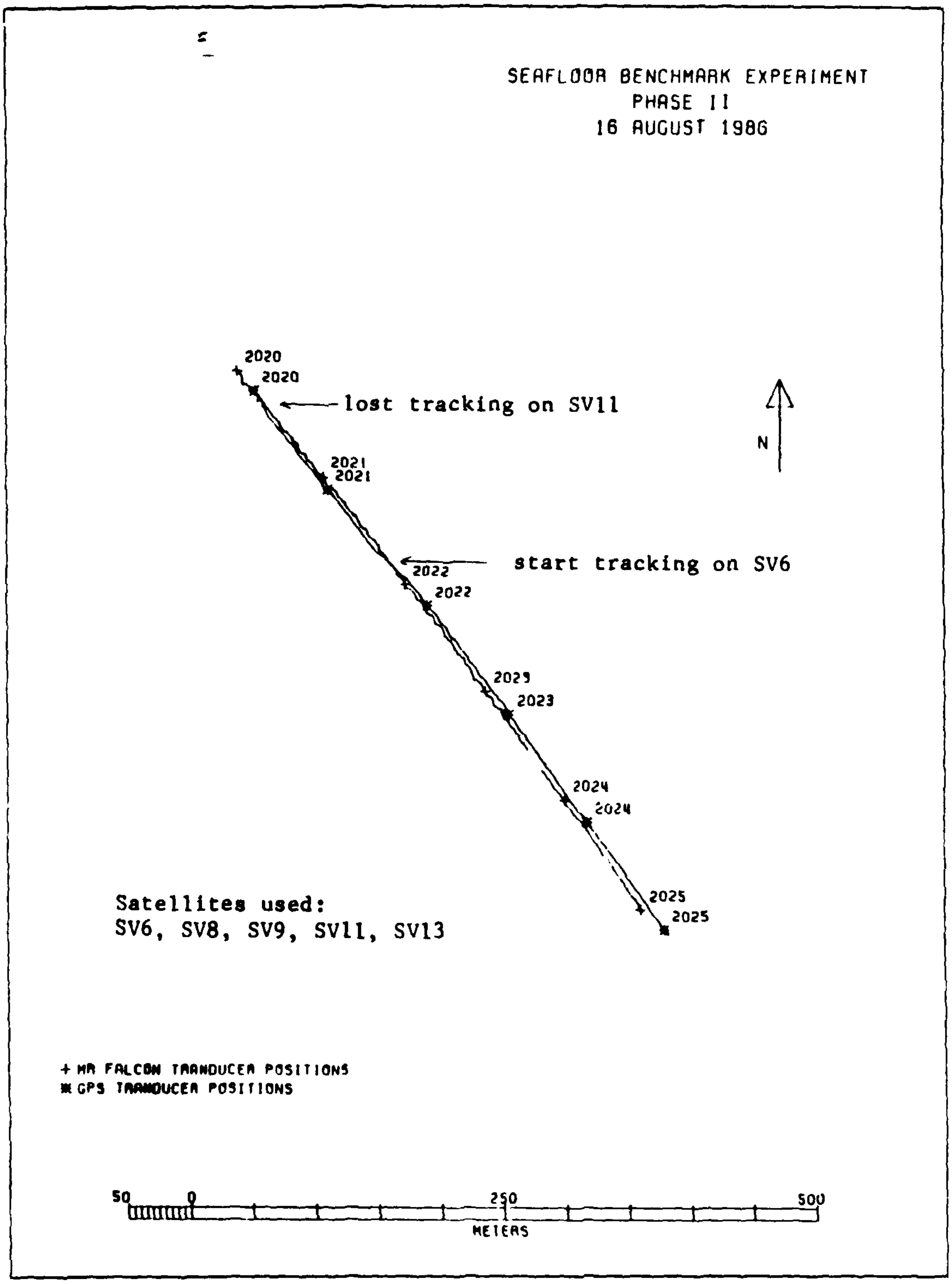



Figure 4.13 Period 10 (Case A). Using all available satellites.

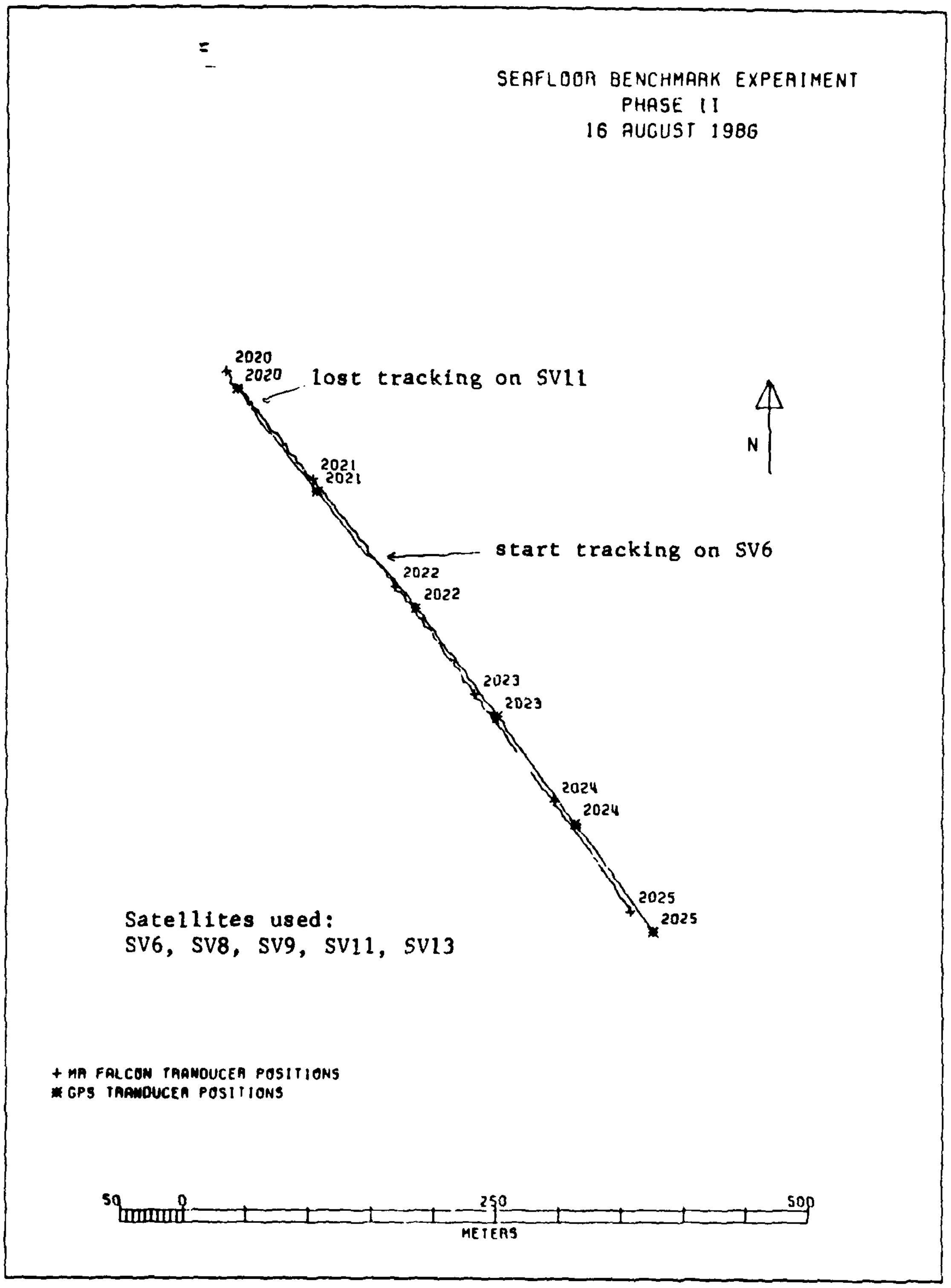



Figure 4.14 Period 10 (Case B). Constraining to geoidal height.

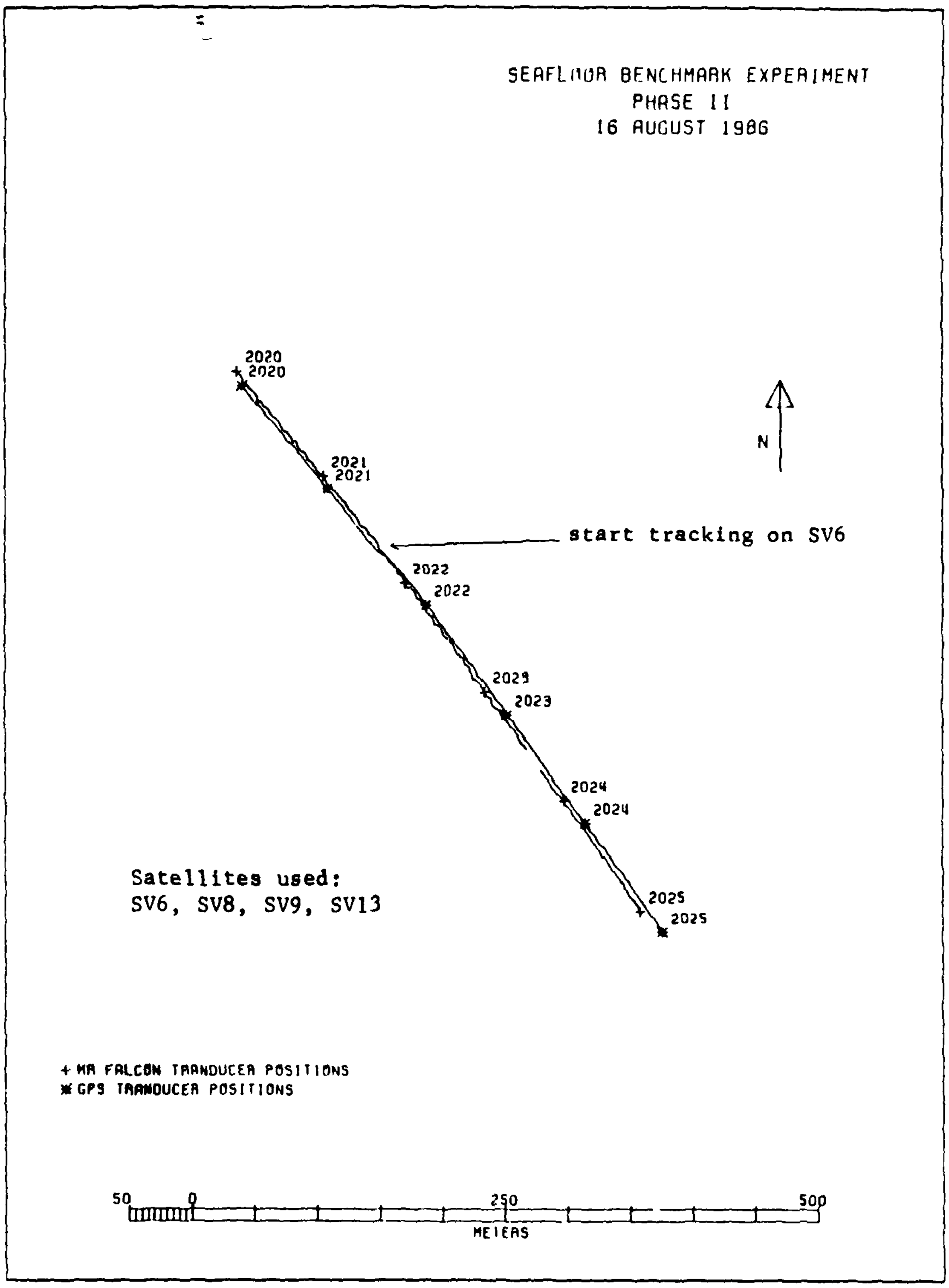



Figure 4.15 Period 10 (Case C). Ignoring SV11.

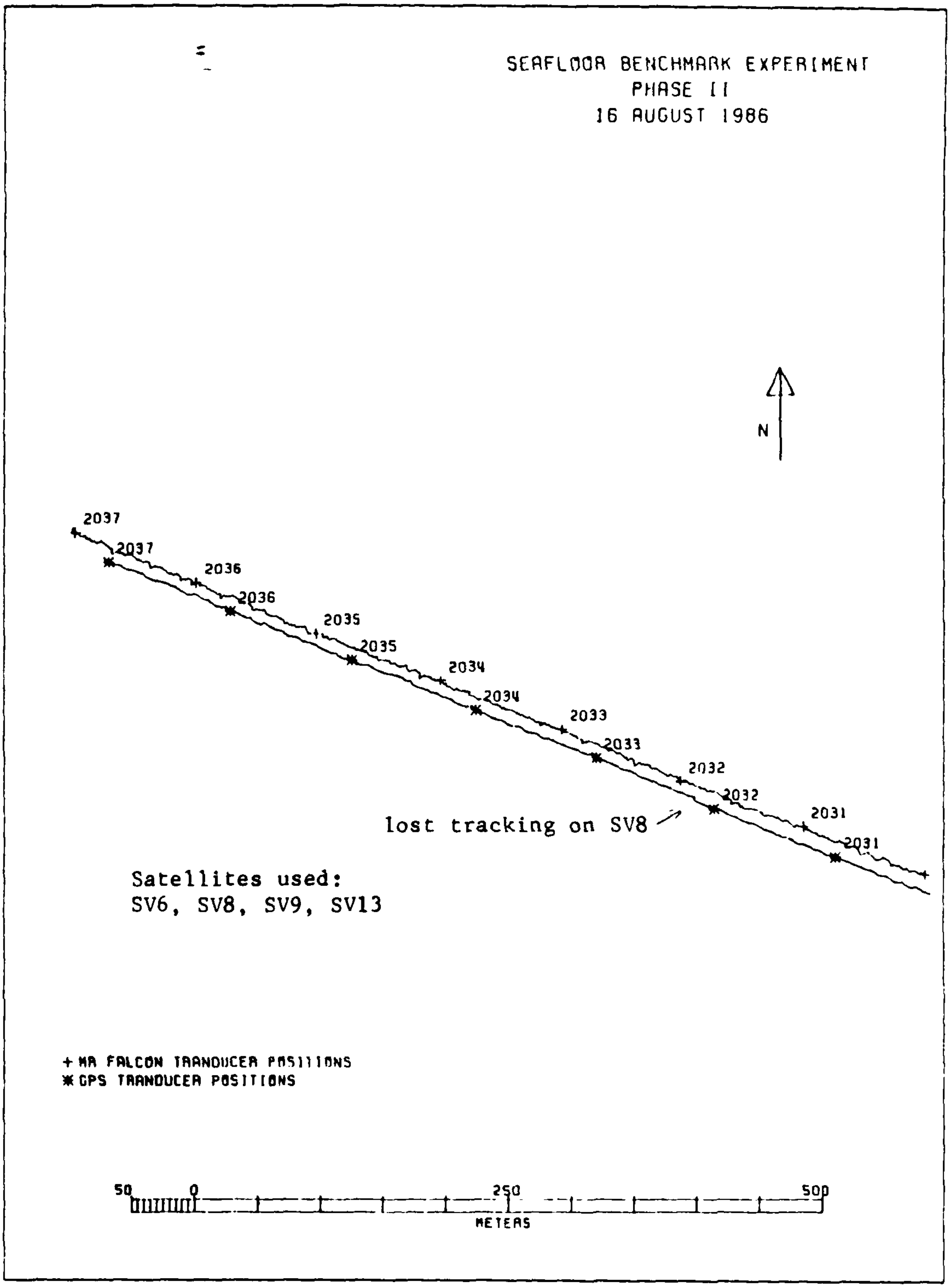



Figure 4.16 Period 11 (Case A). Using all available satellites.

4. **Programs. Inputs and outputs**

Two programs written for data analysis are summarized below:

| | |
|---|---|
| Program: | COMPARE POSITION |
| Input: | Control file with period limits (Appendix K) |
| | File with MR Falcon positions |
| | File with GPS positions |
| Output: | Listing with date, time tag, and GPS geographic positions and differences in UTM coordinates |
| Source: | See Appendix G |

| | |
|---|---|
| Program: | COMPARE PLOT |
| Input: | Control file with period limits (Appendix K) |
| | File with MR Falcon positions |
| | File with GPS positions |
| Output: | Plots of tracks using GPS and MR Falcon data |
| Source: | See Appendix H |

## B. CONCLUSIONS

The results of the data analysis using four satellites with the broadcast ephemeris indicate that the real-time positioning by GPS of a dynamic platform, e.g. a ship, under the best conditions is within 15 m but in most cases 20 m.

Using data from three satellites and constraining the solution to the geoidal height, positional accuracies are within 20 m under the best conditions and 30 m in most of the cases.

It was found that the GPS positions were always southeasterly of the Mini-Ranger positions. Due to lack of sufficient data and due to time limitations, correlation between the geometry of the satellites and ship's heading could not be investigated.

The accuracy of the positions is correlated with the relative motion of the satellites; this was found when SV11 was ignored as in Case C, which improved the solution. If the variations in azimuth and elevation of all satellites are compared for all periods the data was processed, SVs 6 and 11 have variations larger than 110 degrees, while SVs 8, 9 and 13 have variations in azimuth smaller than 35 degrees (Table 2). It

can be seen that both SVs 6 and 11 reach their culmination during the period the data is analyzed. SV6 reaches its culmination around 20:15 and SV11 around 19:50.

When SV11 is approaching culmination, the solution is not improved when the position is constrained to the geoid; after culmination however, application of the constraint improves the solution (Tables 12, 13 and 14).

The degradation in the accuracy of the GPS positions using either SV6 or SV11 is evident in Table 15 where the differences found in these situations are bigger than for positions computed without data from them. It is evident that even in Case C when SV6, with the same characteristics as SV11, is used to compute the position, the differences become larger.

There are some theoretical studies (Landau, 1986) about the selection of satellite configuration in order to get the best results for computed positions. However, with the present data it is not possible to select a best combination, since the data acquisition was limited to a small observational period and a small number of satellites. Currently a way of measuring the effect of the geometry of the satellite configuration is through the analysis of the geometric dilution of precision (GDOP) parameters. These parameters include the position dilution of precision (PDOP), reflecting the dilution of precision in three dimensions, the the horizontal dilution of precision (HDOP), reflecting the dilution of precision in two dimensions, the the vertical dilution of precision (VDOP), reflecting the dilution of precision in the vertical dimension, and the time dilution of precision (TDOP), reflecting the dilution of precision in time (Milliken and Zoller, 1980). Thus, a low PDOP provides a good geometric configuration. Table 16 lists the observed satellites and their GDOP parameters.

It was found that the position of the antenna is important, and in the case of the NSWC TI-4100 receiver some error was caused by shadowing due to the ship's mast when the azimuth of the satellites was close to the course of the ship.

The positions used for comparison with the GPS positions are themselves affected by the noisy signal of the MR Falcon positioning system. This problem could be reduced if more than two LOPs were used in the computation of positions.

TABLE 12

MR FALCON POSITIONS VERSUS GPS POSITIONS.
OBSERVED DIFFERENCES IN METERS DURING PERIOD 3

| Time | | | Case A | | | Case B | | | Case C | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| H | M | S | DX | DY | DP | DX | DY | DP | DX | DY | DP |
| 19 | 25 | 0.7 | 8 | -18 | 19 | 11 | -29 | 31 | -- | -- | -- |
| 19 | 25 | 5.7 | 8 | -17 | 19 | 12 | -27 | 30 | -- | -- | -- |
| 19 | 25 | 10.7 | 9 | -15 | 18 | 12 | -27 | 29 | -- | -- | -- |
| 19 | 25 | 15.7 | 8 | -17 | 19 | 12 | -28 | 30 | -- | -- | -- |
| 19 | 25 | 20.7 | 9 | -16 | 18 | 12 | -27 | 30 | -- | -- | -- |
| 19 | 25 | 25.7 | 9 | -16 | 18 | 12 | -27 | 30 | -- | -- | -- |
| 19 | 25 | 30.7 | 9 | -15 | 18 | 12 | -27 | 29 | -- | -- | -- |
| 19 | 25 | 35.7 | 9 | -16 | 19 | 12 | -27 | 30 | -- | -- | -- |
| 19 | 25 | 40.7 | 10 | -15 | 18 | 13 | -26 | 29 | -- | -- | -- |
| 19 | 25 | 45.7 | 10 | -16 | 18 | 13 | -26 | 30 | -- | -- | -- |

DX, DY differences in the UTM coordinates
DP derived position difference from DX and DY

Case A - using four satellites, or
three satellites with geoidal height constraint
Case B - geoidal height constraint in Case A
Case C - no data during this period

TABLE 13

MR FALCON POSITIONS VERSUS GPS POSITIONS.
OBSERVED DIFFERENCES IN METERS DURING PERIOD 6

| Time | | | Case A | | | Case B | | | Case C | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| H | M | S | DX | DY | DP | DX | DY | DP | DX | DY | DP |
| 19 | 52 | 40.7 | 17 | -22 | 28 | 19 | -22 | 29 | 16 | -21 | 26 |
| 19 | 52 | 41.7 | 16 | -24 | 28 | 18 | -23 | 29 | 15 | -22 | 27 |
| 19 | 52 | 42.7 | 16 | -24 | 29 | 18 | -23 | 30 | 16 | -22 | 27 |
| 19 | 52 | 43.7 | 17 | -22 | 28 | 19 | -23 | 30 | 16 | -22 | 27 |
| 19 | 52 | 44.7 | 15 | -24 | 29 | 16 | -25 | 30 | 14 | -24 | 28 |
| 19 | 52 | 45.7 | 16 | -21 | 27 | 18 | -22 | 29 | 15 | -21 | 26 |
| 19 | 52 | 46.7 | 10 | -27 | 29 | 12 | -28 | 30 | 8 | -27 | 28 |
| 19 | 52 | 47.7 | 14 | -23 | 27 | 15 | -24 | 28 | 8 | -23 | 25 |
| 19 | 52 | 48.7 | 14 | -23 | 27 | 15 | -23 | 27 | 9 | -20 | 22 |
| 19 | 52 | 49.7 | 15 | -22 | 26 | 16 | -21 | 26 | 10 | -18 | 21 |
| 19 | 52 | 50.7 | 17 | -20 | 26 | 18 | -19 | 26 | 12 | -16 | 20 |
| 19 | 52 | 51.7 | 18 | -20 | 27 | 19 | -19 | 27 | 14 | -17 | 21 |
| 19 | 52 | 52.7 | 19 | -19 | 27 | 20 | -19 | 27 | 15 | -17 | 23 |
| 19 | 52 | 53.7 | 19 | -19 | 27 | 20 | -19 | 28 | 16 | -18 | 24 |
| 19 | 52 | 54.7 | 13 | -27 | 30 | 13 | -27 | 31 | 10 | -26 | 28 |
| 19 | 52 | 55.7 | 12 | -26 | 29 | 13 | -26 | 29 | 9 | -25 | 26 |

DX, DY differences in the UTM coordinates
DP derived position difference from DX and DY

Case A - using four satellites, or
three satellites with geoidal height constraint
Case B - geoidal height constraint in Case A
Case C - ignoring SV11 but constraining with
geoidal height

TABLE 14

MR FALCON POSITIONS VERSUS GPS POSITIONS.
OBSERVED DIFFERENCES IN METERS DURING PERIOD 8

| Time H | Time M | Time S | Case A DX | Case A DY | Case A DP | Case B DX | Case B DY | Case B DP | Case C DX | Case C DY | Case C DP |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 7 | 0.7 | 11 | -15 | 19 | 9 | -14 | 17 | 5 | -13 | 14 |
| 20 | 7 | 20.7 | 10 | -17 | 20 | 8 | -15 | 17 | 4 | -14 | 14 |
| 20 | 7 | 40.7 | 10 | -15 | 18 | 9 | -14 | 17 | 4 | -12 | 13 |
| 20 | 8 | 0.7 | 9 | -18 | 20 | 7 | -17 | 18 | 4 | -16 | 16 |
| 20 | 8 | 20.7 | 10 | -17 | 20 | 8 | -16 | 17 | 5 | -14 | 15 |
| 20 | 8 | 40.7 | 10 | -17 | 20 | 8 | -16 | 17 | 4 | -14 | 15 |
| 20 | 9 | 0.7 | 11 | -17 | 20 | 8 | -15 | 17 | 5 | -14 | 15 |
| 20 | 9 | 20.7 | 11 | -17 | 20 | 8 | -15 | 17 | 5 | -14 | 14 |
| 20 | 9 | 40.7 | 11 | -17 | 20 | 8 | -15 | 17 | 5 | -14 | 14 |
| 20 | 10 | 0.7 | 11 | -15 | 19 | 9 | -14 | 16 | 5 | -12 | 13 |
| 20 | 10 | 20.7 | 9 | -17 | 19 | 8 | -16 | 17 | 5 | -14 | 15 |
| 20 | 10 | 40.7 | 11 | -17 | 17 | 9 | -14 | 16 | 5 | -12 | 12 |
| 20 | 11 | 0.7 | 11 | -16 | 20 | 8 | -15 | 17 | 4 | -13 | 13 |
| 20 | 11 | 20.7 | 12 | -16 | 20 | 9 | -14 | 17 | 4 | -13 | 13 |
| 20 | 11 | 40.7 | 12 | -16 | 19 | 8 | -14 | 16 | 4 | -12 | 13 |
| 20 | 12 | 0.7 | 12 | -15 | 19 | 9 | -13 | 16 | 4 | -11 | 12 |

DX, DY differences in the UTM coordinates
DP derived position difference from DX and DY

Case A - using four satellites, or
three satellites with geoidal height constraint
Case B - geoidal height constraint in Case A
Case C - ignoring SV11 but constraining with
geoidal height

TABLE 15

MR FALCON POSITIONS VERSUS GPS POSITIONS.
OBSERVED DIFFERENCES IN METERS DURING PERIOD 10

| Time | | | Case A | | | Case B | | | Case C | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| H | M | S | DX | DY | DP | DX | DY | DP | DX | DY | DP |
| 20 | 20 | 7.7 | 14 | -15 | 20 | 9 | -13 | 15 | 4 | -10 | 11 |
| 20 | 20 | 8.7 | 14 | -15 | 20 | 9 | -13 | 15 | 4 | -10 | 11 |
| 20 | 20 | 9.7 | 11 | -13 | 17 | 8 | -12 | 15 | 4 | -10 | 11 |
| 20 | 20 | 10.7 | 9 | -13 | 15 | 7 | -13 | 14 | 3 | -11 | 11 |
| 20 | 20 | 11.7 | 8 | -12 | 14 | 7 | -12 | 14 | 3 | -10 | 11 |
| 20 | 20 | 12.7 | 7 | -12 | 13 | 6 | -12 | 13 | 3 | -10 | 11 |
| . | . | . | . | . | . | . | . | . | . | . | . |
| 20 | 20 | 44.7 | 4 | -10 | 10 | 4 | -10 | 10 | 4 | -10 | 10 |
| 20 | 20 | 46.7 | 4 | -10 | 10 | 4 | -10 | 10 | 4 | -10 | 10 |
| 20 | 20 | 47.7 | 3 | -11 | 11 | 3 | -11 | 11 | 3 | -11 | 11 |
| . | . | . | . | . | . | . | . | . | . | . | . |
| 20 | 21 | 35.7 | 3 | -10 | 11 | 3 | -10 | 11 | 3 | -10 | 10 |
| 20 | 21 | 36.7 | 3 | -10 | 11 | 3 | -10 | 11 | 3 | -10 | 11 |
| 20 | 21 | 37.7 | 8 | -13 | 15 | 8 | -13 | 15 | 8 | -13 | 15 |
| 20 | 21 | 38.7 | 10 | -14 | 18 | 10 | -14 | 18 | 10 | -14 | 18 |
| 20 | 21 | 39.7 | 12 | -15 | 19 | 12 | -15 | 20 | 12 | -15 | 20 |
| 20 | 21 | 40.7 | 13 | -16 | 21 | 13 | -16 | 20 | 13 | -16 | 21 |

DX, DY differences in the UTM coordinates
DP derived position difference from DX and DY

Case A - using four satellites, or
three satellites with geoidal height constraint
Case B - geoidal height constraint in Case A
Case C - ignoring SV11 but constraining with
geoidal height

TABLE 16

PREDICTED GDOP PARAMETERS
16 AUGUST 1986

| Time | SV set | | | | GDOP | PDOP | HDOP | VDOP | TDOP |
|---|---|---|---|---|---|---|---|---|---|
| 19:00 | 6 | 8 | 9 | 11 | 6.90 | 5.75 | 2.47 | 5.19 | 3.82 |
| 19:20 | 6 | 8 | 9 | 11 | 7.61 | 6.30 | 2.65 | 5.72 | 4.47 |
| 19:40 | 8 | 9 | 11 | 13 | 3.37 | 3.01 | 1.97 | 2.27 | 1.53 |
| 20:20 | 8 | 9 | 11 | 13 | 3.86 | 3.53 | 2.75 | 2.22 | 1.55 |
| | 6 | 8 | 9 | 13 | 3.33 | 2.94 | 1.88 | 2.25 | 1.58 |

# V. RECOMMENDATIONS

GPS data from other days of the Phase II cruise should be used with the modified programs discussed here to further check our conclusions.

Tests should be made in order to find the reason for offsets in a southeasterly direction and evaluate their correlation, if any, with the geometry of the satellites used.

To test the conclusion that the accuracy depends on the large variations of the azimuth of the satellites, SVs other than SV6 and SV11 should be used.

The relation between satellites' culminations during observations and the accuracy of the positions should be further investigated to provide a criterion for satellite selection.

A better antenna site on the ship should be found to avoid shadowing and to minimize the effects of pitch and roll. Antennas of two similar systems should be installed at both high and low elevations to determine the effects of pitch and roll.

The Kalman filter should be improved to avoid the oscillation when data are noisy. Other algorithms should be implemented and their results compared to the results of the KALMN2 program.

To provide a real-time position computation the KALMN2 program or a similar program should be installed in a transportable computer. A system should be designed to have one computer converting and logging the data, another processing and displaying results, saving them or sending them to still another computer or data recording system, and there should be a master system to control the synchronization of time recorded with all data and to control the flow of information.

Processing of the same data should be done using the precise ephemeris to see how the solution is improved.

Processing in differential mode should be done to see how much the solution is improved.

Comparison of data from other receivers should be done to check which type of receiver provides higher accuracy.

Next an experiment should be designed to obtain point or differential positions in real time for moving platforms (survey ship) with little or no shore support.

To allow better evaluation of the GPS data, positions computed with more than two lines of position should be used as reference.

# APPENDIX A
# PROGRAM FALCON. SOURCE LISTING

```
//EZEQUIEL     JOB (0812,9999),'EZEQUIEL',CLASS=C
//*MAIN        ORG=NPGVM1.0812P,LINES=(99),CARDS=(99)
//*FORMAT PR,DDNAME=GO.FT06F001,
//*FORMS=SEP1
//             EXEC FORTVCLG
//FORT.SYSIN  DD *
C
C   AUTHOR: AUGUSTO EZEQUIEL
C   DATE: APRIL 10, 1987
C
C   DESCRIPTION:
C   THE PROGRAM TAKES THE RAW RANGE-RANGE DATA FROM AN INPUT FILE,
C   COMPUTS THE POSITIONS AND AND THE COURSE BETWEEN TWO ANTENNA
C   POSITIONS AND PRINTS THE UTM COORDINATES, THE COMPUTED COURSE
C   AND THE GPS TIME OF EACH OBSERVATION.
C   THE PROGRAM RUNS IN MVS
C   I/O SPECIFICATIONS:  SEE END OF THIS JOB.
C
C   THIS PROGRAM IS RESTRICT AS IS TO THE SEAFLOOR BENCHMARK EXPERIMENT
C   FOR OTHER USES DO NOT FORGET TO ENTER THE COORDINATES OF THE
C   STATIONS AND OTHER PARAMETERS.
C
C   COORDINATES ARE IN WGS72 DATUM.
C
C   THE PROGRAM WILL RUN WITH ANY AMOUNT OF DATA ONLY LIMITED TO DISK
C   SPACE
C
C   ANY BLANK LINES WILL TERMINATE THE PROGRAM  IN ERROR
C
C
C
C
C
      REAL *8 X(2),Y(2),XPOS,YPOS,XOLD,YOLD
      INTEGER LADEG1,LADEG2,LAMIN1,LAMIN2,LODEG1,LODEG2,LOMIN1,LOMIN2
      INTEGER MONTH,YEAR,DAY,HOUR,MIN,LADEG,LAMIN,LODEG,LOMIN
      REAL LASEC1,LASEC2,LOSEC1,LOSEC2,LASEG,LOSEG,SECS
C
C     STATION 1 FERRIER
C
      LADEG1=36
      LAMIN1=33
      LASEC1=53.748
      LODEG1=121
      LOMIN1=53
      LOSEC1=52.939
C
C     STATION 2  DOME ECC
C
      LADEG2=36
      LAMIN2=18
      LASEC2=20.95
      LODEG2=121
      LOMIN2=54
      LOSEC2=00.50
C
C COMPUTE X-Y FOR CONTROL STATIONS
C
      CALL GPUTM(LADEG1,LAMIN1,LASEC1,LODEG1,LOMIN1,LOSEC1,Y(1) ,X(1))
      CALL GPUTM(LADEG2,LAMIN2,LASEC2,LODEG2,LOMIN2,LOSEC2,Y(2) ,X(2))
C
```

```
C END OF INITIAL DATA
C
C
C      COMPUTS THE FIRST POSITION TO HAVE A STARTING POINT FOR
C           EVALUATION OF THE COURSE
C
          READ(50, * ,END=100)  MONTH,DAY,YEAR,HOUR,MIN,SECS,
        * KODE1,RANG1,ISTRE1,KODE2,RANG2,ISTRE2
              CALL RRXY(X,Y,RANG1,RANG2,XOLD,YOLD)
C
C READ IN DATA FROM INPUT FILE
C
   50  CONTINUE
          READ(50, * ,END=100)  MONTH,DAY,YEAR,HOUR,MIN,SECS,
        * KODE1,RANG1,ISTRE1,KODE2,RANG2,ISTRE2
C
C  COMPUTE X-Y AND GP OF RR POSITION
C
              CALL RRXY(X,Y,RANG1,RANG2,XPOS,YPOS)
C
C  COMPUTES THE COURSE
C
               CALL HEAD(XOLD,YOLD,XPOS,YPOS,COURSE,IERR)
C
C         IF LANE JUMPS DOES NOT SAVE THE POSITION
C
C         IF(IERR.LT.0) WRITE(6,1)IERR
C1        FORMAT(I6)
               IF(IERR.LT.0) GOTO 50
C
C      COMPUTES THE GEOGRAPHIC COORDINATES
C
          CALL UTMGP(YPOS,XPOS,LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG)
C
C OUTPUT THE RESULTS
C
          WRITE(6,60)  MONTH,DAY,YEAR,HOUR,MIN,SECS,LADEG,LAMIN,LASEG
        #              ,LODEG,LOMIN,LOSEG,COURSE
   60  FORMAT(2(1X,I2),1X,I4,3(1X,I3,1X,I2,1X,F7.3),1X,F5.0)
C
          WRITE(7) MONTH,DAY,YEAR,HOUR,MIN,SECS,LADEG,LAMIN,LASEG
        #              ,LODEG,LOMIN,LOSEG
C
C      SAVES THE COURSE IN A SEPARATE FILE
C
          WRITE(8) MONTH,DAY,YEAR,HOUR,MIN,SECS,COURSE
C
C      SAVES POSITION FOR COURSE COMPUTATION
C
          XOLD=XPOS
          YOLD=YPOS
          GOTO 50
C
C      END OF PROGRAM
C
  100  CONTINUE
          STOP
          END
C
C*********************************************************************
              SUBROUTINE RRXY(XR,YR,R1,R2,XCO,YCO)
C*********************************************************************
C
          IMPLICIT REAL*8 (A-H,O-Z)
          DIMENSION XR(2),YR(2)
          A = DSQRT((XR(2)-XR(1))**2 + (YR(2)-YR(1))**2)
          CR = (XR(2)-XR(1)) / A
          SR = (YR(2)-YR(1)) / A
          XP = (R1*R1 - R2*R2 + A*A) / (2*A)
          ARG = R1*R1 - XP*XP
```

```
      YP = DSQRT(ARG)
      XCO = XP*CR + YP*SR + XR(1)
      YCO = XP*SR - YP*CR + YR(1)
      RETURN
      END
C
C*****************************************************************
      SUBROUTINE GPUTM(LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG,NORTH,EAST)
C*****************************************************************
C
      DOUBLE PRECISION A,R,N,AP,BP,CP,DP,EP,S,R1,ESQ,ESQP,RM,RP,KO
      DOUBLE PRECISION R2,R3,R4,R5,P,P2,P3,P4,P5,P6,A6,B5,SINSEC
      DOUBLE PRECISION PHI,DLAM,NORTH,EAST,B,PHIMIN,PI,LON
      REAL LASEG,LOSEG
C
C     THIS SUBROUTINE COMPUTS THE UTM COORDINATES OF GP IN WGS 72
C     IN ZONE 10 CENTRAL MERIDIAN 123 00 00 W
C
      CM=-123.0D0
      PHI=DFLOAT(LADEG)+DFLOAT(LAMIN)/60.D0+DBLE(LASEG)/3600.D0
      LON=DFLOAT(LODEG)+DFLOAT(LOMIN)/60.D0+DBLE(LOSEG)/3600.D0
      LON=-LON
      DLAM=(LON-CM)*3600.0D0
C
      A=6378135.0D0
      R=298.26D0
C
      KO=0.9996D0
C
      B = A*(R-1.D0)/R
C
      N = (A-B)/(A+B)
      AP = A*((1.D0-N)+5.D0/4.D0*(N**2-N**3)+81.D0/64.D0*(N**4-N**5))
      BP = 3.D0/2.D0*A*((N-N**2)+7.D0/8.D0*(N**3-N**4)+55.D0/64.D0*N**5)
      CP = 15.D0/16.D0*A*(N**2-N**3+3.D0/4.D0*(N**4-N**5))
      DP = 35.D0/48.D0*A*(N**3-N**4+11.D0/16.D0*N**5)
      EP = 315.D0/512.D0*A*(N**4-N**5)
      PHIMIN = PHI*60.D0*2.908882086660-4
C
      PI=DARCOS(-1.D0)
C
      PHI=PHI/180.D0*PI
C
      S = AP*PHIMIN-BP*DSIN(2.D0*PHI)+CP*DSIN(4.D0*PHI)
     $  - DP*DSIN(6.D0*PHI)+EP*DSIN(8.D0*PHI)
      R1 = KO*S
C
      SINSEC = (1.D0/3600.D0)/180.D0*PI
      SINSEC=DSIN(SINSEC)
C
      ESQ = (A**2-B**2)/A**2
      ESQP = ESQ/(1.D0-ESQ)
      RM = A*(1.D0-ESQ)/(DSQRT(1.D0-ESQ*DSIN(PHI)**2))**3
C
      RP = RM*(1.D0+ESQP*DCOS(PHI)**2)
      R2 = RP*DSIN(PHI)*DCOS(PHI)*SINSEC**2/2.D0*KO*1.D08
      R3 = SINSEC**4*RP*DSIN(PHI)*DCOS(PHI)**3/24.D0*(5.D0-DTAN(PHI)**2
     $ + 9.D0*ESQP*DCOS(PHI)**2+4.D0*ESQP*ESQP*DCOS(PHI)**4)*KO*1.D16
      R4 = RP*DCOS(PHI)*SINSEC*KO*1.D4
      R5 = SINSEC**3*RP*DCOS(PHI)**3/6.D0*(1.D0-DTAN(PHI)**2
     $   + ESQP*DCOS(PHI)**2)*KO*1.D12
C
      P = .0001D0*DLAM
      P2 = P**2
      P3 = P**3
      P4 = P**4
      P5 = P**5
      P6 = P**6
C
      A6 = P6*SINSEC**6*RP*DSIN(PHI)*DCOS(PHI)**5/720.D0
```

```
     $    * (61.D0-58.D0*DTAN(PHI)**2+DTAN(PHI)**4
     $    + 270.D0*ESQP*DCOS(PHI)**2-330.D0*ESQP*DSIN(PHI)**2)*KO*1.D24
      B5 = P5*SINSEC**5*RP*DCOS(PHI)**5/120.D0*(5.D0-18.D0*DTAN(PHI)**2
     $    + DTAN(PHI)**4+14.D0*ESQP*DCOS(PHI)**2
     $    - 58.D0*ESQP*DSIN(PHI)**2)*KO*1.D20
      NORTH=R1+R2*P2+R3*P4+A6
      EAST=(R4*P+R5*P3+B5)+500000.D0
      RETURN
      END
C
C*****************************************************************
      SUBROUTINE HEAD(XOLD,YOLD,XPOS,YPOS,COURSE,IERR)
C*****************************************************************
C
      REAL*8  XOLD,YOLD,XPOS,YPOS
      IERR=0
      DX=XPOS-XOLD
      DY=YPOS-YOLD
      RADIUS=SQRT(DX**2+DY**2)
      IF(RADIUS.GT.20.) IERR=-1
      IF(RADIUS.GT.0.) GO TO 10
      COURSE=0.0
      RETURN
   10 CONTINUE
   20 COURSE= ARCOS(DY/RADIUS)
      COURSE=COURSE*180./3.141592654
      IF(DX.LT.0.) COURSE=360.-COURSE
      RETURN
      END
C
C*****************************************************************
      SUBROUTINE UTMGP(NORTH,EAST,LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG)
C*****************************************************************
C
      DOUBLE PRECISION A,R,N,B, BP,CP,DP,EP,S,R1,ESQ,ESQP,RM,RP,KO
      DOUBLE PRECISION R7,R8,R9,E5,Q,Q2,Q3,Q4,Q5,Q6,D6,AP,SINSEC
      DOUBLE PRECISION R10,DLAM,NORTH,EAST,RPHI,DPHI  ,PHIMIN
      DOUBLE PRECISION EPRIME,DELTA,D6NUM,CM,PHI,LON,PI
      REAL LASEG,LOSEG
C
C     THIS SUBROUTINE COMPUTS THE UTM COORDINATES OF GP IN WGS 72
C     IN ZONE 10 CENTRAL MERIDIAN 123 00 00 W
C
      CM=-123.D00
C
      A=6378135.D00
      R=298.26D00
C
      KO=0.9996D00
C
      PI=DARCOS(-1.D0)
      B = A*(R-1.D0)/R
C
      N = (A-B)/(A+B)
      AP = A*((1.D0-N)+5.D0/4.D0*(N**2-N**3)+81.D0/64.D0*(N**4-N**5))
      BP = 3.D0/2.D0*A*((N-N**2)+7.D0/8.D0*(N**3-N**4)+55.D0/64.D0*N**5)
      CP = 15.D0/16.D0*A*(N**2-N**3+3.D0/4.D0*(N**4-N**5))
      DP = 35.D0/48.D0*A*(N**3-N**4+11.D0/16.D0*N**5)
      EP = 315.D0/512.D0*A*(N**4-N**5)
C
C     FIRST APROXIMATION OF PHI
C
      PHI=NORTH/30.8D0/3600.D0
C
C     COMPUT TRUE MERIDIONAL DIST AND APROXIMATE PHI
C
      DO 100 I=1,8
      PHIMIN=PHI*60.D0*2.908882086660-4
      RPHI=PHI/180.D0*PI
```

```
      S = AP*PHIMIN-BP*DSIN(2.D0*RPHI)+CP*DSIN(4.D0*RPHI)
     $    -DP*DSIN(6.D0*RPHI)+EP*DSIN(8.D0*RPHI)
      R1 = KO*S
      DELTA=NORTH-R1
      PHI=(DELTA/30.8/3600.)+PHI
 100  CONTINUE
      RPHI=PHI/180.D0*PI
C
C
      SINSEC = (1.D0/360000)/180.D0*PI
      SINSEC = DSIN(SINSEC)
C
      ESQ = (A**2-B**2)/A**2
      ESQP = ESQ/(1.D0-ESQ)
      RM = A*(1.D0-ESQ)/(DSQRT(1.D0-ESQ*DSIN(RPHI)**2))**3
C
      RP = RM*(1.D0+ESQP*DCOS(RPHI)**2)
      R7=(DTAN(RPHI)/(2.D0*RP**2*SINSEC))*(1.D0+ESQP*DCOS(RPHI)**2)
     $    *1.D12/KO**2
      R8=(DTAN(RPHI)/(24.D0*RP**4*SINSEC))*(5.D0+3.D0*DTAN(RPHI)**2
     $   +6.D0*ESQP*DCOS(RPHI)**2-6.D0*ESQP*DSIN(RPHI)**2-3.D0*ESQP**2
     $   *DCOS(RPHI)**4-9.D0*ESQP**2*DCOS(RPHI)**2*DSIN(RPHI)**2)
     $   *1.D24/KO**4
      R9=1.D0/DCOS(RPHI)/(RP*SINSEC)*1.D6/KO
      R10=1.D0/DCOS(RPHI)/(6.D0*RP**3*SINSEC)*(1.D0+2.D0*DTAN(RPHI)**2
     $    +ESQP*DCOS(RPHI)**2)*1.D18/KO**3
C
      EPRIME=EAST-500000.D0
      Q = .000001D0*EPRIME
      Q2 = Q**2
      Q3 = Q**3
      Q4 = Q**4
      Q5 = Q**5
      Q6 = Q**6
      D6NUM=Q6*DTAN(RPHI)
      D6=(D6NUM)/(720.D0*RP**6*SINSEC)*(61.D0+90.D0*DTAN(RPHI)**2
     $   +45.D0*DTAN(RPHI)**4+107.D0*ESQP*DCOS(RPHI)**2
     $   -162.D0*ESQP*DSIN(RPHI)**2-45.D0*ESQP*DTAN(RPHI)**2
     $   *DSIN(RPHI)**2)*1.D36/KO**6
      E5=(Q5*1.D0/DCOS(RPHI))/(120.D0*RP**5*SINSEC)*(5.D0+28.D0
     $   *DTAN(RPHI)**2+24.D0*DTAN(RPHI)**4+6.D0*ESQP*DCOS(RPHI)**2
     $   +8.D0*ESQP*DSIN(RPHI)**2)*1.D30/KO**5
C
      DPHI=(-R7*Q2+R8*Q4-D6)/3600.D0
      DLAM=(R9*Q-R10*Q3+E5)/3600.D0
      PHI=PHI+DPHI
      LON=CM+DLAM
      CALL DMS(PHI,LADEG,LAMIN,LASEG)
      CALL DMS(LON,LODEG,LOMIN,LOSEG)
      RETURN
      END
C
C*********************************************************************
      SUBROUTINE DMS(DEC,LDEG,MIN,SEC)
C*********************************************************************
C
      DOUBLE PRECISION DEC,XNUM,XMIN
C
      XNUM=DABS(DEC)
      LDEG=DINT(XNUM)
      XMIN=(XNUM-DFLOAT(LDEG))*60.D0
      MIN=DINT(XMIN)
      XNUM=(XMIN-DFLOAT(MIN))*60.D0
      SEC=SNGL(XNUM)
      IF (LDEG.GE.360) LDEG=LDEG-360
      RETURN
      END
/*
//GO.FT06F001 DD SYSOUT=*
//GO.FT07F001 DD DSN=MSS.S0812.FALCON.ANTENNA.POS,DISP=OLD
```

```
//GO.FT08F001 DD DSN=MSS.S0812.FALCON.COURSE.ROUGH,DISP=OLD
//GO.FT50F001 DD DSN=MSS.S0812.FALCON.DATA(FALCON1),DISP=SHR
//             DD DSN=MSS.S0812.FALCON.DATA(FALCON2),DISP=SHR
//             DD DSN=MSS.S0812.FALCON.DATA(FALCON3),DISP=SHR
//             DD DSN=MSS.S0812.FALCON.DATA(FALCON4),DISP=SHR
//             DD DSN=MSS.S0812.FALCON.DATA(FALCON5),DISP=SHR
//             DD DSN=MSS.S0812.FALCON.DATA(FALCON6),DISP=SHR
//             DD DSN=MSS.S0812.FALCON.DATA(FALCON7),DISP=SHR
//
```

# APPENDIX B
## PROGRAM COURSE SMOOTH. SOURCE LISTING

```
//JOBSMOTH     JOB (0812,9999),'EZEQUIEL',CLASS=C
//*MAIN        ORG=NPGVM1.0812P,LINES=(99),CARDS=(99)
//*FORMAT PR,DDNAME=GO.FT06F001,
//*FORMS=SEP1
//             EXEC FORTVCLG
//FORT.SYSIN  DD *
C
C    AUTHOR: AUGUSTO EZEQUIEL
C    DATE: JANUARY 05, 1986
C
C    DESCRIPTION:
C    THE PROGRAM MAKES THE RUNNING AVERAGE OF THE COURSE COMPUTED
C    BY THE PROGRAM < COMP > IN ORDER TO TAKE OUT THE EFECTS OF THE
C    PITCH AND ROLL EFFECTS.  THE FIRST AND LAST TWO POSITIONS ARE
C    REJECTED AS NO RUNNING AVERAGE IS POSSIBLE FOR THEM.
C    THE PROGRAM RUNS IN MVS
C    I/O SPECIFICATIONS:  SEE END OF THIS JOB.
C
C    THIS PROGRAM IS RESTRICT AS IS TO THE SEAFLOOR BENCHMARK EXPERIMENT

C
C    THE PROGRAM WILL RUN WITH ANY AMOUNT OF DATA ONLY LIMITED TO DISK
C    SPACE
C
C    ANY BLANK LINES WILL TERMINATE THE PROGRAM  IN ERROR
C
C
C
C
C
      REAL COURSE(5),SECS(5)
      INTEGER MONTH(5),YEAR(5),DAY(5),HOUR(5),MIN(5),FLAG
      LOGICAL SAVE
C
C     INITIALIZATION OF FLAGS
C
      SAVE= .FALSE.
      FLAG=1
C
C     READS THE FIRST FIVE COURSES
C
      DO 100 J=1,5
      READ(51,END=1100) MONTH(J),DAY(J),YEAR(J),HOUR(J),
     $ MIN(J),SECS(J),COURSE(J)
 150  FORMAT(2(1X,I2),1X,I4,1X,I2,1X,I2,1X,F4.1,1X,F07.2)
C     WRITE(6,150) MONTH(J),DAY(J),YEAR(J),HOUR(J),
C    $ MIN(J),SECS(J),COURSE(J)
 100  CONTINUE
C
C     AVERAGE THE COURSE
C
  105 AVG=(COURSE(1)+COURSE(2)+COURSE(3)+COURSE(4)+COURSE(5))/5.0
C
C     SAVES THE AVERAGE IN THE MIDDLE POSITION
C
      COURSE(3)=AVG
C
C     DOES NO SAVE THE FIRST TWO POSITONS OF THE FILE AS NO RUNNING
C     AVERAGE EXISTS FOR THEM
C
      IF(SAVE) GOTO 50
C
```

```
      FLAG=FLAG+1
      IF(FLAG.EQ.3) SAVE=.TRUE.
      GOTO 70
C
C     WRITES THE DATA WITH THE AVERAGED COURSE INTO THE FILE
C
   50 WRITE(7) MONTH(1),DAY(1),YEAR(1),HOUR(1),MIN(1),SECS(1),COURSE(1)
C
      WRITE(6,150) MONTH(1),DAY(1),YEAR(1),HOUR(1),
     $                                        MIN(1),SECS(1),COURSE(1)
C
C     MOVES FORWARD THE DATA
C
   70 CONTINUE
      DO 75 J=2,5
      MONTH(J-1)=MONTH(J)
      DAY(J-1)=DAY(J)
      YEAR(J-1)=YEAR(J)
      HOUR(J-1)=HOUR(J)
      MIN(J-1)=MIN(J)
      SECS(J-1)=SECS(J)
      COURSE(J-1)=COURSE(J)
   75 CONTINUE
C
C     READS ONE MORE COURSE
C
      READ(51,END=1000) MONTH(5),DAY(5),YEAR(5),HOUR(5),
     $ MIN(5),SECS(5),COURSE(5)
C
C     GO BACK TO COMPUT A NEW AVERAGE
      GO TO 105
C
C     END OF FILE FOUND DURING THE INPUT OF A FITH COURSE
C     SO SAVES THE REMAINING TWO AVERAGES
1000  CONTINUE
      DO 1001 J=1,2
      WRITE(7,150) MONTH(J),DAY(J),YEAR(J),HOUR(J),
     $ MIN(J),SECS(J),COURSE(J)
      WRITE(6,150) MONTH(J),DAY(J),YEAR(J),HOUR(J),
     $ MIN(J),SECS(J),COURSE(J)
1001  CONTINUE
      STOP
C
C     NO OUTPUT IS MADE IF AN END OF FILE HAS FOUND DURING THE READING
C     OF THE FIRST FIVE COURSES
1100  CONTINUE
      WRITE(6,140)
  140 FORMAT (' ERROR. END OF FILE DURING THE FIRST SET OF COURSES')
      STOP
      END
/*
//GO.FT06F001 DD SYSOUT=*
//GO.FT07F001 DD DSN=MSS.S0812.FALCON.COURSE.SMOOTH,DISP=SHR
//GO.FT51F001 DD DSN=MSS.S0812.FALCON.COURSE.ROUGH,DISP=SHR
//
```

# APPENDIX C

## PROGRAM TRANSDUC FALCON. SOURCE LISTING

```
//JOBTRANS    JOB (0812,9999),'EZEQUIEL',CLASS=C
//*MAIN       ORG=NPGVM1.0812P,LINES=(99),CARDS=(99)
//*FORMAT PR,DDNAME=GO.FT06F001,
//*FORMS=SEP1
//            EXEC FORTVCLG
//FORT.SYSIN  DD *
C
C
C   AUTHOR: AUGUSTO EZEQUIEL
C   DATE: MARCH 04, 1987
C
C   DESCRIPTION:
C
C      THIS PROGRAMS TAKES EACH POSITION OF THE ANTENNA
C      THE COMPUTED COURSE ( FILTERED OR NOT ) ,THE PITCH
C      AND ROLL DATA, AND COMPUTES THE POSITIONS OF THE
C      TRANSDUCER, APLYING THE SEVEN PARAMETER TRANSFORMATION
C      TO THE OFFSETS OF THE TRANSDUCER IN RELATION TO THE ANTENNA
C      CONSIDERED THE CENTER OF COORDINATE SYSTEM AND THEN ADDING
C      THE CORRECTIONS TO THE COORDINATES.
C
C      THE PROGRAM RUNS IN MVS
C
C      I/O SPECIFICATIONS:  SEE END OF THIS JOB.
C
C     THIS PROGRAM IS RESTRICT AS IS TO THE SEAFLOOR BENCHMARK
C     EXPERIMENT
C
C     THE PROGRAM WILL RUN WITH ANY AMOUNT OF DATA ONLY LIMITED TO DISK
C     SPACE
C
C     ANY BLANK LINES WILL TERMINATE THE PROGRAM  IN ERROR
C
C
C
        DOUBLE PRECISION XPOS,YPOS,TIME1,TIME2,TIME3,SECD,SECH,RATE
        DOUBLE PRECISION TIME4, TIME5
        REAL COURSE,PITCH(2),ROLL(2),SEC1(2),SEC2,PIT,ROL,SEC3(2)
        REAL DX,DY,DZ,OFFX,OFFY,OFFZ,HEAD(2),LASEG,LOSEG
        INTEGER MONTH1(2),DAY1(2),YEAR1(2),HOUR1(2),MIN1(2)
        INTEGER MONTH2   ,DAY2   ,YEAR2   ,HOUR2   ,MIN2
        INTEGER MONTH3(2),DAY3(2),YEAR3(2),HOUR3(2),MIN3(2)
        INTEGER LADEG,LAMIN,LODEG,LOMIN
C
C     INITIALIZATION OF CONSTANTS
C
        SECH=3600.D0
        SECD=24.D0*SECH
C
        OFFX=-5.345
        OFFY=-9.453
        OFFZ=-16.152
C
C     READS TWO SETS OF PITCH AND ROLL DATA
C
        READ(51,*,END=100) MONTH1(1),DAY1(1),YEAR1(1),HOUR1(1),MIN1(1),
       $                   SEC1(1),PITCH(1),ROLL(1)
        TIME1=DFLOAT(DAY1(1))*SECD+DFLOAT(HOUR1(1))*SECH
       $       + DFLOAT(MIN1(1))*60.D0+DBLE(SEC1(1))
C
        READ(51,*,END=100) MONTH1(2),DAY1(2),YEAR1(2),HOUR1(2),MIN1(2),
```

```
     $                       SEC1(2),PITCH(2),ROLL(2)
      TIME2=DFLOAT(DAY1(2))*SECD+DFLOAT(HOUR1(2))*SECH
     $       + DFLOAT(MIN1(2))*60.D0+DBLE(SEC1(2))
C
C     READS TWO SETS OF COURSE
C
      READ(52,END=100) MONTH3(1),DAY3(1),YEAR3(1),HOUR3(1),MIN3(1),
     $                       SEC3(1),HEAD(1)
      TIME4=DFLOAT(DAY3(1))*SECD+DFLOAT(HOUR3(1))*SECH
     $       + DFLOAT(MIN3(1))*60.D0+DBLE(SEC3(1))
C
      READ(52,END=100) MONTH3(2),DAY3(2),YEAR3(2),HOUR3(2),MIN3(2',
     $                       SEC3(2),HEAD(2)
      TIME5=DFLOAT(DAY3(2))*SECD+DFLOAT(HOUR3(2))*SECH
     $       + DFLOAT(MIN3(2))*60.D0+DBLE(SEC3(2))
C
C      READS ONE POSITION OF THE SHIP
C
   20 READ(50,END=100) MONTH2,DAY2,YEAR2,HOUR2,MIN2,SEC2,
     $            LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG
C
      TIME3=DFLOAT(DAY2)*SECD+DFLOAT(HOUR2)*SECH
     $       + DFLOAT(MIN2)*60.D0+DBLE(SEC2)
C
C      POSITION IN TIME BETWEEN THE TWO SETS OF PITCH AND ROLL DATA
C             AND THE TWO SETS OF COURSE DATA
   25 CONTINUE
C
C       POSITION TO EARLY FOR PITCH AND ROLL DATA
C
      IF(TIME3.GE.TIME1) GO TO 40
      WRITE(6,30) MONTH2,DAY2,YEAR2,HOUR2,MIN2,SEC2
   30 FORMAT(' PSN @ ',I2,1X,I2,1X,I4,1X,I2,1X,I2,1X,F4.1,
     $ ' REJECTED. NO PITCH AND ROLL DATA')
      GOTO 20
C
C       POSITION TO EARLY FOR PITCH AND ROLL DATA
C
   40 CONTINUE
      IF(TIME3.GE.TIME4) GO TO 60
      WRITE(6,50) MONTH2,DAY2,YEAR2,HOUR2,MIN2,SEC2
   50 FORMAT(' PSN @ ',I2,1X,I2,1X,I4,1X,I2,1X,I2,1X,F4.1,
     $ ' REJECTED. NO COURSE DATA')
      GOTO 20
C
C     POSITION LATER THAN THE SECOND SET OF PITCH AND ROLL DATA
C
   60 CONTINUE
      IF(TIME3.LE.TIME2) GOTO 70
C
C     MOVES THE PITCH AND ROLL DATA TO THE FIRST SET
C
      MONTH1(1)=MONTH1(2)
      DAY1(1)=DAY1(2)
      YEAR1(1)=YEAR1(2)
      HOUR1(1)=HOUR1(2)
      MIN1(1)=MIN1(2)
      SEC1(2)=SEC1(2)
      PITCH(1)=PITCH(2)
      ROLL(1)=ROLL(2)
      TIME1=TIME2
C
C     READS A SECOND SET OF PITCH AND ROLL DATA
C
      READ(51,*,END=100) MONTH1(2),DAY1(2),YEAR1(2),HOUR1(2),MIN1(2),
     $                       SEC1(2),PITCH(2),ROLL(2)
      TIME2=DFLOAT(DAY1(2))*SECD+DFLOAT(HOUR1(2))*SECH
     $       + DFLOAT(MIN1(2))*60.D0+DBLE(SEC1(2))
      GOTO 25
C
```

```
C
C     POSITION LATER THAN THE SECOND SET OF COURSE DATA
C
   70 CONTINUE
      IF(TIME3.LE.TIME5) GOTO 80
C
C     MOVES THE COURSE DATA TO THE FIRST SET
C
      MONTH3(1)=MONTH3(2)
      DAY3(1)=DAY3(2)
      YEAR3(1)=YEAR3(2)
      HOUR3(1)=HOUR3(2)
      MIN3(1)=MIN3(2)
      SEC3(2)=SEC3(2)
      HEAD(1)=HEAD(2)
      TIME4=TIME5
C
C     READS A SECOND SET OF PITCH AND ROLL DATA
C
      READ(52,END=100) MONTH3(2),DAY3(2),YEAR3(2),HOUR3(2),MIN3(2),
     $                 SEC3(2),HEAD(2)
      TIME5=DFLOAT(DAY3(2))*SECD+DFLOAT(HOUR3(2))*SECH
     $      + DFLOAT(MIN3(2))*60.D0+DBLE(SEC3(2))
      GOTO 25
C
C     POSITION WITHIN THE TWO SETS IN TIME
C
   80 RATE=(TIME3-TIME1)/(TIME2-TIME1)
      PIT=PITCH(1)+(PITCH(2)-PITCH(1))*RATE
      ROL=ROLL(1)+(ROLL(2)-ROLL(1))*RATE
      RATE=(TIME3-TIME4)/(TIME5-TIME4)
      COURSE=HEAD(1)+(HEAD(2)-HEAD(1))*RATE
C
C     COMPUTS THE CORRECTIONS AND THE POSITIONS OF THE TRANSDUCER
C
      CALL PTH(OFFX,OFFY,OFFZ,COURSE,PIT,ROL,DX,DY,DZ)
C
C     COMPUTES THE UTM COORDINATES
C
      CALL GPUTM(LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG,YPOS,XPOS)
C
      XPOS=XPOS+DX
      YPOS=YPOS+DY
C
C     CONVERTS BACK TO GP
C
      CALL UTMGP(YPOS,XPOS,LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG)
C
C     OUTPUTS THE RESULT
C
      WRITE(7) MONTH2,DAY2,YEAR2,HOUR2,MIN2,SEC2,
     *                          LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG
C
C     WRITE(6,90) MONTH2,DAY2,YEAR2,HOUR2,MIN2,SEC2,
C    *                          LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG
   90 FORMAT(2(1X,I2),1X,I4,1X,I2,1X,I2,1X,F4.1,2(1X,I3,1X,I2,1X,F7.4))
C
C     READS ONE MORE POSITION
      GOTO 20
C
C     END OF PROGRAM
C
  100 CONTINUE
      STOP
      END
C
      SUBROUTINE PTH(XOFF,YOFF,ZOFF,COURSE,PITCH,ROLL,DX,DY,DZ)
C
C     THIS SUBROUTINE COMPUTES THE CORRECTIONS TO THE
C     COORDINATES DUE TO THE OFSET OF ANTENA IN RELATION
```

```
C     TO THE TRANSDUCER
C
         PI=ARCOS(-1.0)
         ROLL=ROLL*PI/180.
         PITCH=PITCH*PI/180.
         COURSE=COURSE*PI/180.
C
C     CHANGE SIGNAL OF ORIGINAL DATA TO MATCH THE RIGHT HAND
C     SYSTEM CONVECTION
C
         ROLL=-ROLL
C
         COSPHI= COS(ROLL)
         SINPHI= SIN(ROLL)
         COSK= COS(COURSE)
         SINK= SIN(COURSE)
         COSW= COS(PITCH)
         SINW= SIN(PITCH)
C
        DX = XOFF * COSPHI * COSK +
      $      YOFF * ( COSW * SINK + SINW * SINPHI * COSK ) +
      $      ZOFF * ( SINW * SINK - COSW * SINPHI * COSK )
C
        DY = XOFF * COSPHI * SINK * (-1.) +
      $      YOFF * ( COSW * COSK - SINW * SINPHI * SINK ) +
      $      ZOFF * ( SINW * COSK + COSW * SINPHI * SINK )
C
        DZ = XOFF * SINPHI -
      $      YOFF * (  SINW * COSPHI ) +
      $      ZOFF * ( COSW * COSPHI )
        RETURN
        END
C
C
        SUBROUTINE UTMGP(NORTH,EAST,LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG)
C
        DOUBLE PRECISION A,R,N,B, BP,CP,DP,EP,S,R1,ESQ,ESQP,RM,RP,KO
        DOUBLE PRECISION R7,R8,R9,E5,Q,Q2,Q3,Q4,Q5,Q6,D6,AP,SINSEC
        DOUBLE PRECISION R10,DLAM,NORTH,EAST,RPHI,DPHI ,PHIMIN
        DOUBLE PRECISION EPRIME,DELTA,D6NUM,CM,PHI,LON,PI
        REAL LASEG,LOSEG
C
C     THIS SUBROUTINE COMPUTS THE UTM COORDINATES OF GP IN WGS 72
C     IN ZONE 10 CENTRAL MERIDIAN 123 00 00 W
C
        CM=-123.0D0
C
        A=6378135.0D0
        R=298.26D0
C
        KO=0.9996D0
C
        PI=DARCOS(-1.D0)
        B = A*(R-1.D0)/R
C
        N = (A-B)/(A+B)
        AP = A*((1.D0-N)+5.D0/4.D0*(N**2-N**3)+81.D0/64.D0*(N**4-N**5))
        BP = 3.D0/2.D0*A*((N-N**2)+7.D0/8.D0*(N**3-N**4)+55.D0/64.D0*N**5)
        CP = 15.D0/16.D0*A*(N**2-N**3+3.D0/4.D0*(N**4-N**5))
        DP = 35.D0/48.D0*A*(N**3-N**4+11.D0/16.D0*N**5)
        EP = 315.D0/512.D0*A*(N**4-N**5)
C
C     FIRST APROXIMATION OF PHI
C
        PHI=NORTH/30.8D0/3600.D0
C
C     COMPUT TRUE MERIDIONAL DIST AND APROXIMATE PHI
C
        DO 100 I=1,8
```

```
      PHIMIN=PHI*60.D0*2.908882086660-4
      RPHI=PHI/180.D0*PI
      S = AP*PHIMIN-BP*DSIN(2.D0*RPHI)+CP*DSIN(4.D0*RPHI)
     $    -DP*DSIN(6.D0*RPHI)+EP*DSIN(8.D0*RPHI)
      R1 = KO*S
      DELTA=NORTH-R1
      PHI=(DELTA/30.8/3600.)+PHI
  100 CONTINUE
      RPHI=PHI/180.D0*PI
C
C
      SINSEC = (1.D0/360000)/180.D0*PI
      SINSEC = DSIN(SINSEC)
C
      ESQ = (A**2-B**2)/A**2
      ESQP = ESQ/(1.D0-ESQ)
      RM = A*(1.D0-ESQ)/(DSQRT(1.D0-ESQ*DSIN(RPHI)**2))**3
C
      RP = RM*(1.D0+ESQP*DCOS(RPHI)**2)
      R7=(DTAN(RPHI)/(2.D0*RP**2*SINSEC))*(1.D0+ESQP*DCOS(RPHI)**2)
     $    *1.D12/KO**2
      R8=(DTAN(RPHI)/(24.D0*RP**4*SINSEC))*(5.D0+3.D0*DTAN(RPHI)**2
     $   +6.D0*ESQP*DCOS(RPHI)**2-6.D0*ESQP*DSIN(RPHI)**2-3.D0*ESQP**2
     $   *DCOS(RPHI)**4-9.D0*ESQP**2*DCOS(RPHI)**2*DSIN(RPHI)**2)
     $   *1.D24/KO**4
      R9=1.D0/DCOS(RPHI)/(RP*SINSEC)*1.D6/KO
      R10=1.D0/DCOS(RPHI)/(6.D0*RP**3*SINSEC)*(1.D0+2.D0*DTAN(RPHI)**2
     $    +ESQP*DCOS(RPHI)**2)*1.D18/KO**3
C
      EPRIME=EAST-500000.D0
      Q = .000001D0*EPRIME
      Q2 = Q**2
      Q3 = Q**3
      Q4 = Q**4
      Q5 = Q**5
      Q6 = Q**6
      D6NUM=Q6*DTAN(RPHI)
      D6=(D6NUM)/(720.D0*RP**6*SINSEC)*(61.D0+90.D0*DTAN(RPHI)**2
     $   +45.D0*DTAN(RPHI)**4+107.D0*ESQP*DCOS(RPHI)**2
     $   -162.D0*ESQP*DSIN(RPHI)**2-45.D0*ESQP*DTAN(RPHI)**2
     $   *DSIN(RPHI)**2)*1.D36/KO**6
      E5=(Q5*1.D0/DCOS(RPHI))/(120.D0*RP**5*SINSEC)*(5.D0+28.D0
     $   *DTAN(RPHI)**2+24.D0*DTAN(RPHI)**4+6.D0*ESQP*DCOS(RPHI)**2
     $   +8.D0*ESQP*DSIN(RPHI)**2)*1.D30/KO**5
C
      DPHI=(-R7*Q2+R8*Q4-D6)/3600.D0
      DLAM=(R9*Q-R10*Q3+E5)/3600.D0
      PHI=PHI+DPHI
      LON=CM+DLAM
      CALL DMS(PHI,LADEG,LAMIN,LASEG)
      CALL DMS(LON,LODEG,LOMIN,LOSEG)
      RETURN
      END
C
      SUBROUTINE GPUTM(LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG,NORTH,EAST)
C
      DOUBLE PRECISION A,R,N,AP,BP,CP,DP,EP,S,R1,ESQ,ESQP,RM,RP,KO
      DOUBLE PRECISION R2,R3,R4,R5,P,P2,P3,P4,P5,P6,A6,B5,SINSEC
      DOUBLE PRECISION PHI,DLAM,NORTH,EAST,B,PHIMIN,PI,LON
      REAL LASEG,LOSEG
C
C    THIS SUBROUTINE COMPUTS THE UTM COORDINATES OF GP IN WGS 72
C    IN ZONE 10 CENTRAL MERIDIAN 123 00 00 W
C
      CM=-123.D0
      PHI=DFLOAT(LADEG)+DFLOAT(LAMIN)/60.D0+DBLE(LASEG)/3600.D0
      LON=DFLOAT(LODEG)+DFLOAT(LOMIN)/60.D0+DBLE(LOSEG)/3600.D0
      LON=-LON
      DLAM=(LON-CM)*3600.D0
C
```

```
      A=6378135.0D0
      R=298.26D0
C
      KO=0.9996D0
C
      B = A*(R-1.D0)/R
C
      N = (A-B)/(A+B)
      AP = A*((1.D0-N)+5.D0/4.D0*(N**2-N**3)+81.D0/64.D0*(N**4-N**5))
      BP = 3.D0/2.D0*A*((N-N**2)+7.D0/8.D0*(N**3-N**4)+55.D0/64.D0*N**5)
      CP = 15.D0/16.D0*A*(N**2-N**3+3.D0/4.D0*(N**4-N**5))
      DP = 35.D0/48.D0*A*(N**3-N**4+11.D0/16.D0*N**5)
      EP = 315.D0/512.D0*A*(N**4-N**5)
      PHIMIN = PHI*60.D0*2.908882086660-4
C
      PI=DARCOS(-1.D0)
C
      PHI=PHI/180.D0*PI
C
      S = AP*PHIMIN-BP*DSIN(2.D0*PHI)+CP*DSIN(4.D0*PHI)
     $  - DP*DSIN(6.D0*PHI)+EP*DSIN(8.D0*PHI)
      R1 = KO*S
C
      SINSEC = (1.D0/3600.D0)/180.D0*PI
      SINSEC=DSIN(SINSEC)
C
      ESQ = (A**2-B**2)/A**2
      ESQP = ESQ/(1.D0-ESQ)
      RM = A*(1.D0-ESQ)/(DSQRT(1.D0-ESQ*DSIN(PHI)**2))**3
C
      RP = RM*(1.D0+ESQP*DCOS(PHI)**2)
      R2 = RP*DSIN(PHI)*DCOS(PHI)*SINSEC**2/2.D0*KO*1.D08
      R3 = SINSEC**4*RP*DSIN(PHI)*DCOS(PHI)**3/24.D0*(5.D0-DTAN(PHI)**2
     $ + 9.D0*ESQP*DCOS(PHI)**2+4.D0*ESQP*ESQP*DCOS(PHI)**4)*KO*1.D16
      R4 = RP*DCOS(PHI)*SINSEC*KO*1.D4
      R5 = SINSEC**3*RP*DCOS(PHI)**3/6.D0*(1.D0-DTAN(PHI)**2
     $   + ESQP*DCOS(PHI)**2)*KO*1.D12
C
      P = .0001D0*DLAM
      P2 = P**2
      P3 = P**3
      P4 = P**4
      P5 = P**5
      P6 = P**6
C
      A6 = P6*SINSEC**6*RP*DSIN(PHI)*DCOS(PHI)**5/720.D0
     $   * (61.D0-58.D0*DTAN(PHI)**2+DTAN(PHI)**4
     $   + 270.D0*ESQP*DCOS(PHI)**2-330.D0*ESQP*DSIN(PHI)**2)*KO*1.D24
      B5 = P5*SINSEC**5*RP*DCOS(PHI)**5/120.D0*(5.D0-18.D0*DTAN(PHI)**2
     $   + DTAN(PHI)**4+14.D0*ESQP*DCOS(PHI)**2
     $   - 58.D0*ESQP*DSIN(PHI)**2)*KO*1.D20
      NORTH=R1+R2*P2+R3*P4+A6
      EAST=(R4*P+R5*P3+B5)+500000.D0
      RETURN
      END
C
      SUBROUTINE DMS(DEC,LDEG,MIN,SEC)
C
      DOUBLE PRECISION DEC,XNUM,XMIN
C
      XNUM=DABS(DEC)
      LDEG=DINT(XNUM)
      XMIN=(XNUM-DFLOAT(LDEG))*60.D0
      MIN=DINT(XMIN)
      XNUM=(XMIN-DFLOAT(MIN))*60.D0
      SEC=SNGL(XNUM)
      IF (LDEG.GE.360) LDEG=LDEG-360
      RETURN
      END
/*
```

```
//GO.FT06F001 DD SYSOUT=*
//GO.FT07F001 DD DSN=MSS.S0812.FALCON.TRANSDUC.POS,DISP=SHR
//GO.FT50F001 DD DSN=MSS.S0812.FALCON.ANTENNA.POS,DISP=SHR
//GO.FT51F001 DD DSN=MSS.S0812.PITROLL,DISP=SHR
//GO.FT52F001 DD DSN=MSS.S0812.SDAS.COURSE,DISP=SHR
//
```

# APPENDIX D
## PROGRAM PLOT. SOURCE LISTING

```
//EZEQUIEL     JOB (0812,9999),'EZEQUIEL',CLASS=C
//             EXEC FRTVCLGP
//FORT.SYSIN   DD *
C
C      PROGRAM PLOT
C
C      RUNS IN FORTRAN VS
C
C      AUTHOR:  AUGUSTO EZEQUIEL
C
C      DATE : 26 JANUARY 1987
C
C      THIS PROGRAM MAKES A PLOT OF THE POSITIONS OF THE SHIP
C
C
         DOUBLE PRECISION XPOS,YPOS,XLEFT,YLEFT,TIME1,TIME2,SECD,SECH
         REAL SECS,XPLT,YPLT,BLXH,BLYH,SCALE,VALUE,LASEG,LOSEG
         INTEGER MONTH,YEAR,DAY,HOUR,MIN,IPEN,LADEG,LAMIN,LODEG,LOMIN
C
C      PLOTTER INITIALIZATION
C
         CALL PLOTS (0,0,0)
         CALL PLOT (2.,2.,-3)
         IPEN=3
C
C      DIMENSIONS OF SHEET, LEFT CORNER AND SCALES
C
         BLXH=36.
         BLYH=49.
         XLEFT=564800.D0
         YLEFT=4037000.D0
         SCALE=1./10000.
C
C      INITIALIZATION OF CONSTANTS
C
         TIME1=0.D0
         SECH=3600.D0
         SECD=24.D0*SECH
C
C      GRID
C
C
         CALL PLOT (0.1,0.1,3)
         CALL PLOT (0.1,BLYH-0.1,2)
         CALL PLOT (BLXH-0.1,BLYH-0.1,2)
         CALL PLOT (BLXH-0.1,0.1,2)
         CALL PLOT (0.1,0.1,2)
C
C      TITLE
C
         CALL TITLE
C
C      SCALE
C
         CALL METER(SCALE)
C
C      READ THE DATA
C
    10 CONTINUE
         READ(51,END=50)MONTH,DAY,YEAR,HOUR,
        $ MIN,SECS,LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG
```

```
C
C     COMPUTES THE UTM COORDINATES
C
         CALL GPUTM(LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG,YPOS,XPOS)
C
C     COMPUTES THE TIME IN SECS
C
         TIME2=SECD*FLOAT(DAY)+SECH*FLOAT(HOUR)+60.D0*FLOAT(MIN)+SECS
C
C     COMPUTES THE PLOTTER COORDINATES
C
         XPLT=(XPOS-XLEFT)*SCALE*100.
         YPLT=(YPOS-YLEFT)*SCALE*100.
C
C     TESTE IF INSIDE AREA
C
         IF(XPLT.LT.0.) GOTO 30
         IF(YPLT.LT.0.) GOTO 30
         IF(XPLT.GT.BLXH) GOTO 30
         IF(YPLT.GT.BLYH) GOTO 30
C
C     TESTS IF POSITIONS ARE AWAY MORE THEN 10 SECS IN TIME
C
         IF(TIME2-TIME1.GT.10.D0) IPEN=3
         TIME1=TIME2
C
C     PLOTS THE POSITION
C
         CALL PLOT(XPLT,YPLT,IPEN)
         IPEN=2
C
C     PLOTS THE TIME EVERY 05 MINUTES
C
         IF(MOD(MIN,05).GT.0.OR.IFIX(SECS).GT.0) GO TO 10
         VALUE=FLOAT(HOUR)*100+FLOAT(MIN)
         CALL NUMBER(XPLT+0.15,YPLT+0.15,0.25,VALUE,0.,-1)
         CALL SYMBOL(XPLT,YPLT,0.15,3,0.,-1)
         GOTO 10
C
C     PEN UP WHILE THE POSITIONS ARE OUT OF THE SHEET
C
   30 IPEN=3
         GOTO 10
C
C     END OF PLOT
C
   50 CALL PLOT(0.,0.,+999)
         STOP
         END
C
         SUBROUTINE METER(SCALE)
C
         XO=24.0
         YO=2.0
         CALL PLOT(XO,YO,-3)
C
         DO 10 J=1,12
         XP= FLOAT(J)-1.0
         CALL PLOT(XP,0.0,3)
         CALL PLOT(XP,0.25,2)
   10 CONTINUE
C
         DO 20 J=1,9
         XP=FLOAT(J)*0.1
         CALL PLOT(XP,0.0,3)
         CALL PLOT(XP,0.2,2)
   20 CONTINUE
C
         CALL PLOT(0.,0.0,3)
         CALL PLOT(11.,0.,2)
```

```
      CALL PLOT(0.,0.2,3)
      CALL PLOT(11.,.2,2)
C
      VALUE=1./SCALE/100.
      CALL NUMBER(-0.25,0.27,0.25,VALUE,0.0,-1)
      CALL NUMBER(0.95,0.27,0.25,0.0,0.0,-1)
      VALUE=5.0/SCALE/100.
      CALL NUMBER(5.775,0.27,0.25,VALUE,0.0,-1)
      VALUE=10.0/SCALE/100.
      CALL NUMBER(10.7,0.27,0.25,VALUE,0.0,-1)
      CALL SYMBOL(5.5,-0.50,.25,6HMETERS,0.0,6)
C
      CALL SYMBOL(5.5,24.0,2.0,62,0.0,-1)
      CALL SYMBOL(5.7,24.5,0.4,85,0.0,-1)
      XO=-XO
      YO=-YO
      CALL PLOT(XO,YO,-3)
C
      RETURN
      END
C
      SUBROUTINE TITLE
C
      XO=26.5
      YO=43.05
      CALL PLOT(XO,YO,-3)
C
      CALL SYMBOL(00.0,3.5,0.25,29H  NAVAL POSTGRADUATE SCHOOL  ,0.,29)
C
      CALL SYMBOL(00.0,3.0,0.25,29HSEAFLOOR BENCHMARK EXPERIMENT,0.,29)
C
C
      CALL SYMBOL(00.0,2.5,0.25,29H          PHASE II           ,0.,29)
C
      CALL SYMBOL(00.0,2.0,0.25,29H        R/V POINT SUR        ,0.,29)
C
      CALL SYMBOL(00.0,1.5,0.25,29H      16/17 AUGUST 1986      ,0.,29)
C
C*    CALL SYMBOL(00.0,1.0,0.25,29H       GESAR SOLUTIONS       ,0.,29)
C
      CALL SYMBOL(00.0,1.0,0.25,29H           TI4100            ,0.,29)
C
C*    CALL SYMBOL(00.0,1.0,0.25,29H     MINI RANGER FALCON      ,0.,29)
C
      CALL SYMBOL(00.0,0.5,0.25,29H     ANTENNA  POSITIONS      ,0.,29)
C
C*    CALL SYMBOL(00.0,0.5,0.25,29H    TRANSDUCER POSITIONS     ,0.,29)
C
C
      CALL SYMBOL(00.0,0.0,0.25,29H     LCDR AUGUSTO EZEQUIEL   ,0.,29)
C
      CALL PLOT(-0.2,-0.2,3)
      CALL PLOT(-0.2,3.95,2)
      CALL PLOT(7.5,3.95,2)
      CALL PLOT(7.5,-0.2,2)
      CALL PLOT(-0.2,-0.2,2)
C
      XO=-XO
      YO=-YO
      CALL PLOT(XO,YO,-3)
C
      RETURN
      END
C
C
C
C
      SUBROUTINE GPUTM(LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG,NORTH,EAST)
C
      DOUBLE PRECISION A,R,N,AP,BP,CP,DP,EP,S,R1,ESQ,ESQP,RM,RP,KO
```

```
      DOUBLE PRECISION R2,R3,R4,R5,P,P2,P3,P4,P5,P6,A6,B5,SINSEC
      DOUBLE PRECISION PHI,DLAM,NORTH,EAST,B,PHIMIN,PI,LON
      REAL LASEG,LOSEG
C
C     THIS SUBROUTINE COMPUTS THE UTM COORDINATES OF GP IN WGS 72
C     IN ZONE 10 CENTRAL MERIDIAN 123 00 00 W
C
      CM=-123.0D0
      PHI=DFLOAT(LADEG)+DFLOAT(LAMIN)/60.D0+DBLE(LASEG)/3600.D0
      LON=DFLOAT(LODEG)+DFLOAT(LOMIN)/60.D0+DBLE(LOSEG)/3600.D0
      LON=-LON
      DLAM=(LON-CM)*3600.0D0
C
      A=6378135.0D0
      R=298.26D0
C
      KO=0.9996D0
C
      B = A*(R-1.D0)/R
C
      N = (A-B)/(A+B)
      AP = A*((1.D0-N)+5.D0/4.D0*(N**2-N**3)+81.D0/64.D0*(N**4-N**5))
      BP = 3.D0/2.D0*A*((N-N**2)+7.D0/8.D0*(N**3-N**4)+55.D0/64.D0*N**5)
      CP = 15.D0/16.D0*A*(N**2-N**3+3.D0/4.D0*(N**4-N**5))
      DP = 35.D0/48.D0*A*(N**3-N**4+11.D0/16.D0*N**5)
      EP = 315.D0/512.D0*A*(N**4-N**5)
      PHIMIN = PHI*60.D0*2.908882086660-4
C
      PI=DARCOS(-1.D0)
C
      PHI=PHI/180.D0*PI
C
      S = AP*PHIMIN-BP*DSIN(2.D0*PHI)+CP*DSIN(4.D0*PHI)
     $  - DP*DSIN(6.D0*PHI)+EP*DSIN(8.D0*PHI)
      R1 = KO*S
C
      SINSEC = (1.D0/3600.D0)/180.D0*PI
      SINSEC=DSIN(SINSEC)
C
      ESQ = (A**2-B**2)/A**2
      ESQP = ESQ/(1.D0-ESQ)
      RM = A*(1.D0-ESQ)/(DSQRT(1.D0-ESQ*DSIN(PHI)**2))**3
C
      RP = RM*(1.D0+ESQP*DCOS(PHI)**2)
      R2 = RP*DSIN(PHI)*DCOS(PHI)*SINSEC**2/2.D0*KO*1.D08
      R3 = SINSEC**4*RP*DSIN(PHI)*DCOS(PHI)**3/24.D0*(5.D0-DTAN(PHI)**2
     $ + 9.D0*ESQP*DCOS(PHI)**2+4.D0*ESQP*ESQP*DCOS(PHI)**4)*KO*1.D16
      R4 = RP*DCOS(PHI)*SINSEC*KO*1.D4
      R5 = SINSEC**3*RP*DCOS(PHI)**3/6.D0*(1.D0-DTAN(PHI)**2
     $    + ESQP*DCOS(PHI)**2)*KO*1.D12
C
      P = .0001D0*DLAM
      P2 = P**2
      P3 = P**3
      P4 = P**4
      P5 = P**5
      P6 = P**6
C
      A6 = P6*SINSEC**6*RP*DSIN(PHI)*DCOS(PHI)**5/720.D0
     $    * (61.D0-58.D0*DTAN(PHI)**2+DTAN(PHI)**4
     $    + 270.D0*ESQP*DCOS(PHI)**2-330.D0*ESQP*DSIN(PHI)**2)*KO*1.D24
      B5 = P5*SINSEC**5*RP*DCOS(PHI)**5/120.D0*(5.D0-18.D0*DTAN(PHI)**2
     $    + DTAN(PHI)**4+14.D0*ESQP*DCOS(PHI)**2
     $    - 58.D0*ESQP*DSIN(PHI)**2)*KO*1.D20
      NORTH=R1+R2*P2+R3*P4+A6
      EAST=(R4*P+R5*P3+B5)+500000.D0
      RETURN
      END
/*
//GO.PLOTPARM DD  *
```

```
 &PLOT XMIN=0.,XMAX=38.,YMIN=0.,YMAX=51.,SCALE=1.,UNITS=2.540 &END
//GO.FT06F001 DD SYSOUT=*
//GO.FT51F001 DD DSN=MSS.S0812.GPS.POS.ANTENNA,DISP=SHR
//
```

# APPENDIX E
## PROGRAM CVFICA. SOURCE LISTING

```
//JOBCVFI      JOB (0812,9999),'EZEQUIEL',CLASS=C
//*MAIN        ORG=NPGVM1.0812P,LINES=(99),CARDS=(99)
//*FORMAT PR,DDNAME=GO.FT06F001,
//*FORMS=SEP1
//             EXEC FORTVCLG
//FORT.SYSIN  DD *
        PROGRAM CVFICA
C   AUTHOR: AUGUSTO EZEQUIEL
C   DATE: MARCH 17, 1987
C
C   DESCRIPTION:
C    THIS PROGRAM CONVERTS THE FICA FILES INTO THE
C    INPUT FORMAT OF THE KALMN PROGRAM AND GIVES
C    GENERAL INFORMATION ABOUT THE DATA
C
        DOUBLE PRECISION FPI(500),TP,PB,HD,RL1OFF,RL2OFF
        DOUBLE PRECISION Q1,Q2,PI,C,VOS,K1,K31,K32,TLDLL,TLPLL
        DOUBLE PRECISION PDBPC,PDBC,CN1(4),CN2(4),CR1(4),CR2(4)
        DOUBLE PRECISION DOP1(4),DOP2(4),BLC,BPDC,SGR1(4),SGR2(4)
        DOUBLE PRECISION SGD1(4),SGD2(4),K2,K4,TT,M,AG,ESQ
        DOUBLE PRECISION TOCS,AS(3),ADC,CRSS,DNS,MOS,CUCS,ES,CUSS
        DOUBLE PRECISION SQAS,TOES,CICS,OMEGS,CISS,IOS,CRCS,WS
        DOUBLE PRECISION DLAT,DLOG,DHT
        DOUBLE PRECISION OMEDS,ADE,IDOTS,X,Y,Z,ROBL
        REAL LASEC,LOSEC,SEC
        INTEGER INTG(500),BLOCK,TYPE,NCI,NII,NFI,LAMIN,LOMIN,LADEG,LODEG
        INTEGER TRACER,MQVEL(4),ISAT(4),INDEX,SAT,IWKNOS,IEDATS,NSAT
        INTEGER IO,STDAY,MONTH,YEAR,HOUR,MIN,DAY
        INTEGER STAT(4)
        CHARACTER*8  CHI(500),TITLE(10)
        CHARACTER*5  BLK
        LOGICAL SAVE,FIRST
C
C     SETS DEFAULT METEO DATA
C
        DATA TP,PB,HD /15.,980.,75./
C
C     SETS THE PARAMETERS OF WGS72
C
        DATA AG, ROBL /6378.135000,298.26D0/
C
C     FLAG TO SAVE DATA ONLY WHEN THERE IS NAVIGATION DATA
C                FOR ALL TRACERS
C
        SAVE=.FALSE.
C
C     FLAG TO SAVE INFORMATION DATA AS TYPE 1 ONLY ON FIRST
C                CASSETTE
C
        FIRST=.TRUE.
C
C     ECCENTRICITY SQUARED OF REFERENCE ELLIPSOID
C
        ESQ=(2.D0-(1.D0/ROBL))/ROBL
C
C
C
        Q1=154.D0
        Q2=120.D0
C
C    COMPUTS THE VALUE OF PI IN DOUBLE PRECISION
```

```
C
         PI=DARCOS(-1.D0)
C
C      SPEED OF LIGHT   (KM/SEC)
C
         C=299792.458D0
C
C      NOMINAL SATELITE FREQUENCY
C
         VOS=10.23D6
C
C     CALCULATION OF CONSTANTS TO BE USED IN THE SGIMA COMPUTATIONS
C
         K1=(C/VOS)**2
         K31=(C/(2.D0*PI*VOS*Q1))**2
         K32=(C/(2.D0*PI*VOS*Q2))**2
C
C
C
         RL1OFF=-6000.D0
         RL2OFF=7600.D0
C
C
C
         M=4.D0
         TLDLL=.7D0
         TLPLL=.7D0
         PDBPC=100.D0
         PDBC=100.D0
C
C      SETS THE FLAGS FOR NOT HAVING THE EPHEMIS DATA
C
         DO  3 I=1,4
   3   STAT(I)=0
C
C      PRINTS OUT THE IDENTIFICATION OF THE PROGRAM
C
         WRITE(6,2)
     2  FORMAT(1H1,/////////
        # ,/,'          ******************************************************'
        # ,/,'          ******************************************************'
        # ,/,'          **                                                  **'
        # ,/,'          **  OUTPUT OF THE PROGRAM CVFICA THAT CONVERTS      **'
        # ,/,'          **  THE FICA FILES TO A FORMAT READABLE BY THE      **'
        # ,/,'          **          PROGRAM KALMN2                          **'
        # ,/,'          **                                                  **'
        # ,/,'          ******************************************************'
        # ,/,'          ******************************************************'
        # ,//////////)
C
C
C      READS THE TITLE FROM THE FILE AND CONTROL INFORMATION
C
         READ(31,5,END=2000)TITLE
         WRITE(6,5) TITLE
         READ(31,5,END=2000)TITLE
         WRITE(6,5,END=2000) TITLE
  5    FORMAT(10A8)
         READ(31,*,END=2000) MONTH,STDAY,YEAR
         WRITE(6,6) MONTH,STDAY,YEAR
   6   FORMAT(///,
        # ' DATE OF STARTING GPS WEEK (MONTH DAY YEAR) ',I3,I3,I5)
C
C      INPUTS THE DATA  FROM THE COMMAND FILE
C
         READ(31,*,END=2000) NSAT, K2, K4
         READ(31,*,END=2000) X,Y,Z
         WRITE(6,1) NSAT,K2,K4,X,Y,Z
  1    FORMAT (' NUMBER OF TRACERS          ',I20,/,
        #        ' RANGE SIGMA BIAS FACTOR    ',E20.8,/,
```

```
     #        ' DOPPLER SIGMA BIAS FACTOR ',E20.8,/,
     #        ' ESTIMATE RECEIVER POSITION',/,
     #        '                        X COORD',F20.6,/,
     #        '                        Y COORD',F20.6,/,
     #        '                        Z COORD',F20.6,/)
C
C*************************************************************
C**   INPUT OF A FICA BLOCK                                 **
C*************************************************************
C
C     READS THE CONTROL BLOCK INFORMATION
C
10    READ(50,20,END=2000) BLK,BLOCK,NFI,NII,NCI
20    FORMAT(A5,4I5)
C
C     READS THE FLOATING PART DATA IF ANY
C
         IF (NFI.EQ.0) GOTO 35
         READ(50,30,END=2000) (FPI(I),I=1,NFI)
30    FORMAT(4D20.16)
C
C     READS THE INTEGER PART IF ANY
C
35    CONTINUE
         IF (NII.EQ.0) GOTO 45
         READ(50,40,END=2000) (INTG(I),I=1,NII)
40    FORMAT(6I12)
C
C     READS CHARACTER PART DATA  IF ANY
C
45    CONTINUE
         IF (NCI.EQ.0) GOTO 55
         READ(50,50,END=2000) (CHI(I),I=1,NCI)
50    FORMAT(10(A8))
55    CONTINUE
         IF (BLOCK.NE.6) GOTO 100
C*************************************************************
C**   TRACING DATA                                          **
C*************************************************************
C
C     USER EPOCH TIME OF PSEUDO RANGE
C
         TT=FPI(3)
C
C     COMPUTES THE DATE
C
         CALL SUB(TT,DAY,HOUR,MIN,SEC)
         DAY=DAY+STDAY
C
C     IF NO EPHMERIS DATA AVOIDS COMPUTATIONS
C
         IF(.NOT.SAVE) GOTO 10
C
C     L1 CARRIER SIGNAL TO NOISE
C
         CN1(1)=FPI(4)
         CN1(2)=FPI(5)
         CN1(3)=FPI(6)
         CN1(4)=FPI(7)
C
C     L2 CARRIER SIGNAL TO NOISE
C
         CN2(1)=FPI(8)
         CN2(2)=FPI(9)
         CN2(3)=FPI(10)
         CN2(4)=FPI(11)
C
C     L1 PSEUDO RANGE  (KM IN FICA FILES CONVERTED TO SECONDS FOR KALMN2)
C
         CR1(1)=FPI(12)/C
```

```
      CR1(2)=FPI(13)/C
      CR1(3)=FPI(14)/C
      CR1(4)=FPI(15)/C
C
C     L2 PSEUDO RANGE  (KM IN FICA FILES CONVERTED TO SECONDS FOR KALMN2)
C
      CR2(1)=FPI(16)/C
      CR2(2)=FPI(17)/C
      CR2(3)=FPI(18)/C
      CR2(4)=FPI(19)/C
C
C     L1 CARRIER DOPLER PHASE
C
      DOP1(1)=FPI(20)
      DOP1(2)=FPI(21)
      DOP1(3)=FPI(22)
      DOP1(4)=FPI(23)
C
C     L2 CARRIER DOPLER PHASE
C
      DOP2(1)=FPI(24)
      DOP2(2)=FPI(25)
      DOP2(3)=FPI(26)
      DOP2(4)=FPI(27)
C
C     SV PRN OF EACH TRACER
C
      ISAT(1)=INTG(1)
      ISAT(2)=INTG(2)
      ISAT(3)=INTG(3)
      ISAT(4)=INTG(4)
C
C     L1,L2 QUALITY FACTOR (TRACER,FREQUENCY)
C
      MQVEL(1)=INTG(9)-INTG(13)
      MQVEL(2)=INTG(10)-INTG(14)
      MQVEL(3)=INTG(11)-INTG(15)
      MQVEL(4)=INTG(12)-INTG(16)
C
C     IF ANY ERRORS FLAGS THE DATA OF THE SATELLITE
C
      DO 120 INDEX=1,NSAT
C
C     ERRORS IN SIGNAL
C
      IF( MQVEL(INDEX).EQ.0) GOTO 114
      MQVEL(INDEX)=15
        I1=8+INDEX
        I2=12+INDEX
      WRITE(6,110) MONTH,DAY,YEAR,HOUR,MIN,SEC,INDEX,INTG(I1),INTG(I2)
  110 FORMAT(/,' **-**-** WARNING **-**-** AT ',
     #  2(I2,1X),I4,1X,2(I2,':'),F5.2,/,
     #  ' DATA FROM TRACER ',
     # I2,' GESAR BAD STATUS ',I5,1X,I5)
C
      MQVEL(INDEX)=15
C
C     IF THE DATA IS ALREADY BAD NO NEED TO TEST THE SATELLITE
C
      GOTO 120
C
C     NON EXISTENT SATELITE DATA FOR THAT TRACER
C
  114 CONTINUE
      IF( STAT(INDEX).EQ.ISAT(INDEX)) GO TO 120
C
C
      WRITE(6,115) MONTH,DAY,YEAR,HOUR,MIN,SEC,INDEX,
     #                                ISAT(INDEX),STAT(INDEX)
115   FORMAT (/, ' ** * **   WARNING   ** * **   AT ',
```

```
      *              2X,I2,1X,I2,1X,I4,2X,I2,':',I2,':',F5.2,/,
      * '        TRACKING TRACER ',I2,' SV ',I2,
      *' EXISTING NAV DATA FOR SV ',I2,' FLAGED BAD QUALITY DATA')
       MQVEL(INDEX)=15
  120 CONTINUE
C
C     COMPUTS THE SIGMAS
C
       DO 150 INDEX=1,NSAT
       IF( MQVEL(INDEX).NE.0) GOTO 150
C
C     CALCULATE L1 AND L2 SIGMA RANGE
C
       BLC=TLDLL
       BPDC=PDBPC
       SGR1(INDEX)=((BLC*M)/(10.**(CN1(INDEX)/10.)))
      *         * (.5*BPDC/(10.**(CN1(INDEX)/10.)))*K1+K2
       SGR2(INDEX)=((BLC*M)/(10.**(CN2(INDEX)/10.)))
      *         * (.5*BPDC/(10.**(CN2(INDEX)/10.)))*K1+K2
C
C     CALCULATE L1 AND L2 SIGMA  DOPPLER DATA
C
       BLC=TLPLL
       BPDC=PDBC
       SGD1(INDEX)=((BLC*M)/(10.**(CN1(INDEX)/10.)))
      *      * (1.+(.5*BPDC/(10.**(CN1(INDEX)/10.))))*K31+K4
       SGD2(INDEX)=((BLC*M)/(10.**(CN2(INDEX)/10.)))
      *      * (1.+(.5*BPDC/(10.**(CN2(INDEX)/10.))))*K32+K4
150   CONTINUE
C
C     OUTPUT THE DATA TO THE FILE IF THERE IS NAV DATA
C
       TYPE=3
       WRITE(7) TYPE
       WRITE(7) TT, ISAT, CR1, CR2, DOP1, DOP2,
      *             SGR1, SGR2, SGD1, SGD2, MQVEL
C
C     GO TO READ ANOTHER BLOCK
C
       GOTO 10
C
  100 CONTINUE
       IF (BLOCK.NE.109) GOTO 200
C*******************************************************************
C**   NAVIGATION DATA   (AS TRANSMITED)                           **
C*******************************************************************
C
       TRACER=INTG(1)
       SAT=INTG(2)
C
C     GO TO READ ANOTHER BLOCK
C
       GOTO 10
C
  200 CONTINUE
       IF (BLOCK.NE.9) GOTO 300
C
C*******************************************************************
C**   NAVIGATION DATA   (DECODED SUBFRAMES 1 TO 3)                **
C*******************************************************************
C
C     DAY OF WEEK
C
       IWKNOS=DINT(FPI(6))
C**   IWKNOS=IAND(IWKNOS,1777B)
C
C     SV HEALTH
C
       IEDATS=DINT(FPI(9))
C
```

```
C     CLOCK EPOCH    (GPS SECONDS OF WEEK)
C
         TOCS=FPI(13)
C
C     CLOCK BIAS      (SEC)
C
         AS(1)=FPI(16)
C
C     CLOCK DRIFT    (SEC/SEC)
C
         AS(2)=FPI(15)
C
C     CLOCK DRIFT RATE (SEC/SEC**2)
C
         AS(3)=FPI(14)
C
C     AGE OF DATA (CLOCK)  (SEC)
C
         ADC=FPI(10)
C
C     RADIAL SINE CORRECTION (DIVIDED BY 1000. TO GET KM)
C
         CRSS=FPI(27)/1000.
C
C     CORRECTION TO MEAN MOTION (RADIANS/SECONDS)
C
         DNS=FPI(28)
C
C     MEAN ANOMALY AT EPOCH      (RADIANS)
C
         MOS=FPI(29)
C
C     IN TRACK COSINE AMPLITUDE   (RADIANS)
C
         CUCS=FPI(30)
C
C     ECCENTRICITY
C
         ES=FPI(31)
C
C     IN TRACK SINE AMPLITUDE  (RADIANS)
C
         CUSS=FPI(32)
C
C     SQUARE ROOT OF SEMI-MAJOR AXIS CONVERTED TO SQR OF KM
C
         SQAS=FPI(33)*FPI(33)
         SQAS=SQAS/1000.D0
         SQAS=DSQRT(SQAS)
C
C     TIME OF EPOCH     (GPS SECONDS OF WEEK)
C
         TOES=FPI(34)
C
C     INCLINATION COSINE CORRECTION   (RADIANS)
C
         CICS=FPI(46)
C
C     RIGHT ASCENSION NODE     (RADIANS)
C
         OMEGS=FPI(47)
C
C     INCLINATION SINE CORRECTION  (RADIANS)
C
         CISS=FPI(48)
C
C     INCLINATION          (RADIANS)
C
         IOS=FPI(49)
C
```

```
C     RADIAL COSINE ADJUSTMENT (DIVIDED BY 1000 TO GET KM )
C
         CRCS=FPI(50)/1000.
C
C     ARGUMENT OF PERIGEE     (RADIANS)
C
         WS=FPI(51)
C
C     RIGHT ASCENSION OF ASCENDING NODE (TIME DERIVATIVE)
C                                     (RADIANS/SEC)
         OMEDS=FPI(52)
C
C     AGE OF DATA          (SEC)
C
         ADE=FPI(26)
C
C     INCLINATION TIME DERIVATIVE     (RADIANS/SECONDS)
C
         IDOTS=FPI(54)
C
C    SETS THE FLAG FOR EXISTANCE OF NAV DATA FOR THIS SATELITTE
C
         STAT(TRACER)=SAT
C
C     TESTS IF THERE IS ENOUGH NAV DATA
C
         SAVE=.TRUE.
         DO 210 INDEX=1,NSAT
         IF(STAT(INDEX).EQ.0) SAVE=.FALSE.
210   CONTINUE
C
C     OUTPUTS THE DATA
C
         TYPE=2
         WRITE(7) TYPE
         WRITE(7) TRACER,SAT,AS(1),AS(2),AS(3),CICS,CISS
     #            ,CRCS,CRSS,CUCS,CUSS,DNS,ES,IDOTS,IOS,MOS
     #            ,OMEDS,OMEGS,SQAS,ADE,TOCS,TOES,IWKNOS,WS
     #            ,IEDATS,ADC
C
C      INFORMS THAT NAVIGATION DATA WAS RECEIVED FOR THIS SATELLITE
C
C
           WRITE(6,220) TRACER,SAT,MONTH,DAY,YEAR,HOUR,MIN,SEC
  220  FORMAT(///,' ****************************************',/
     #        ,' **            NAVIGATIONAL               **',/,
     #    ' ** DATA FROM TRACER ',I2,'  SV ',I3,' RECEIVED **',/,
     #    ' ** ',7X,I2,1X,I2,1X,I4,2X,I2,':',I2,':',F5.2,7X,'**',/,
     #      ' ****************************************',///)
C
C     PRINTS OUT THE WARNING WHEN THE HEALTH IS NOT GOOD
C
         IF( FPI(9) .NE. 0.0 ) WRITE(6,201) TRACER,SAT,FPI(9)
   201 FORMAT(/////,'**************************************'
     #,' TRACER ',I3,' SV ',I3,' HEALTH STATUS ' ,F15.6,
     #            ,'**************************************')
C
C     GO TO READ ANOTHER BLOCK
C
         GOTO 10
C
300   CONTINUE
         IF (BLOCK.NE.101) GOTO 400
C
C*************************************************************
C**   BLOCK 1 PLUS INPUT DATA                              **
C*************************************************************
C
C     PRESSURE
C
```

```
         PB=FPI(1)
C
C     TEMPERATURE
C
         TP=FPI(2)
C
C     HUMIDITY
C
         HD=FPI(3)
C
C     TESTE FOR BAD WEATHER DATA. CHANGE TO STANDARD VALUES BAD DATA
C
         IF (( PB .LT. 800. ) .OR. ( PB .GT. 1200. )) PB = 980.
         IF (( TP .LT. -99. ) .OR. ( TP .GT.  +99. )) TP =  15.
         IF (( HD .LT.   1. ) .OR. ( HD .GT.  100. )) HD =  75.
C
C     OUTPUTS THE DATA   FOR THE FIRST TIME
C
         IF(.NOT.FIRST) GOTO 10
C
         TYPE=1
         WRITE(7) TYPE
         WRITE(7) RL1OFF,RL2OFF,PB,TP,HD,X,Y,Z
C
C     SETS THE FLAG
C
         FIRST=.FALSE.
C
C     GO TO READ ANOTHER BLOCK
C
         GOTO 10
C
400   CONTINUE
         IF (BLOCK.NE.3) GOTO 460
C
C*****************************************************************
C**   GESAR SOLUTION                                            **
C*****************************************************************
C
C     SOLUTION USER EPOCH TIME
C
         TT=FPI(2)
C
C     IF NO EPHMERIS DATA DOES NOT KEEP THE DATA
C
         IF(.NOT.SAVE) GOTO 10
C
C     COORDINATES OF RECEIVER
C
         X=FPI(3)
         Y=FPI(4)
         Z=FPI(5)
C
C     COMPUTES THE DATA
C
         CALL SUB(TT,DAY,HOUR,MIN,SEC)
         DAY=DAY+STDAY
C
C     ONLY PRINTS POSITIONS IF UNCOMENTED
C
C     WRITE(6,450) MONTH,DAY,YEAR,HOUR,MIN,SEC,X,Y,Z
450   FORMAT (/, ' GESAR SOLUTION AT (MM DAY YYYY HH:MM:SS.SSS)',
     #             2X,I2,1X,I2,1X,I4,2X,I2,':',I2,':',F5.2,
     #/,' PSN COORD X, Y, Z (KM) ',F14.3,'    ',F14.3,'    ',F14.3)
C
C     CONVERTS TO LATITUDE / LATITUDE / HT
C
         CALL XYLLH(X,Y,Z,AG,ESQ,DLAT,DLOG,DHT,PI)
C
C     PRINTS THE RESULTS
```

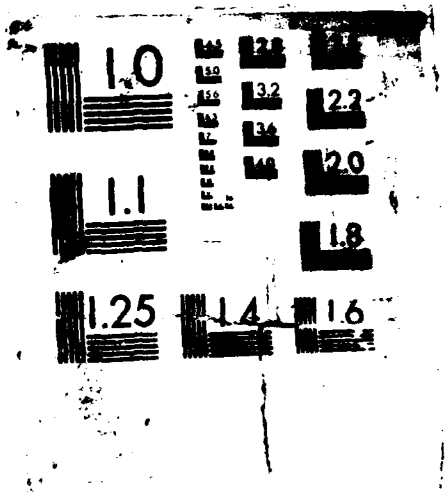
```
C
C     WRITE(6,455) DLAT,DLOG,DHT
  455 FORMAT(' LAT, LON, HT (DEG, DEG, KM) ',2F17.12,2X,F12.7)
C
C     CONVERTS LATITUDE TO DEGREES MINUTES AND SECONDS
C
         CALL DMS(DLAT,LADEG,LAMIN,LASEC)
C
C     CONVERTS LONGITUDE TO DEGREES MINUTES AND SECONDS
C               IN A RANGE 0 TO 180
         IF (DLOG.GT.180.D0) DLOG=360.D0-DLOG
         CALL DMS(DLOG,LODEG,LOMIN,LOSEC)
C
C     WRITE(6,456) LADEG,LAMIN,LASEC,LODEG,LOMIN,LOSEC
  456 FORMAT(' LAT, LON (DEG MIN SEC, DEG MIN SEG) ',2(2I4,1X,F7.4),/)
C
C     OUTPUTS THE DATA TO A FILE
C
         WRITE(8) MONTH,DAY,YEAR,HOUR,MIN,SEC,
     #                 LADEG,LAMIN,LASEC,LODEG,LOMIN,LOSEC
C
C
C     GO TO READ ANOTHER BLOCK
C
         GOTO 10
C
460   CONTINUE
         IF (BLOCK.NE.13) GOTO 470
C
C***********************************************************************
C**   TAPE HEADER/TRAILOR                                            **
C***********************************************************************
C
         WRITE(6,461)
461   FORMAT(/,5X,'******************************',/,
     #         5X,'**   TAPE HEADER/TRAILOR   **',/,
     #         5X,'******************************',/)
         IF( INTG(1).EQ.1) WRITE (6,462)
         IF( INTG(1).EQ.2) WRITE (6,463)
         IF( INTG(1).EQ.4) WRITE (6,464)
         IF( INTG(1).EQ.8) WRITE (6,465)
 462  FORMAT('     BEGINING OF DATA SET',/)
 463  FORMAT('     END OF DATA SET',/)
 464  FORMAT('     BEGINING OF CASSETTE',/)
 465  FORMAT('     END OF CASSETTE',/)
         WRITE(6,466) INTG(2),INTG(3)
 466  FORMAT('     CASSETTE ',I5,' IN DATA SET',/,
     #       '     CASSETTE SEQUENCE NUMBER ',I5)
C
C     GO TO READ ANOTHER BLOCK
C
         GOTO 10
C
470   CONTINUE
         IF (BLOCK.NE.11) GOTO 480
C
C     IF NO EPHMERIS DATA DOES NOT KEEP THE DATA SO NO NEED TO
C               INFORM THE USER
C
         IF(.NOT.SAVE) GOTO 10
C
C***********************************************************************
C**   RECEIVER ERROR BLOCK                                           **
C***********************************************************************
C
C
         WRITE(6,471) MONTH,DAY,YEAR,HOUR,MIN,SEC
471   FORMAT(/,'        ********************************************',/,
     #      '        **   ERROR BLOCK RECEIVED AFTER :           **',/,
     #      '        **',9X,2(I2,1X),I4,2X,2(I2,':'),F5.2,8X,'**',/,
```

```
     *        '        ********************************************',/)
C
        WRITE (6,472)(INTG(I),I=1,NII)
 472  FORMAT('          ERROR LOG MESSAGE TI ICD FORMAT * 1',I8,/,
     *        '                                           * 2',I8,/,
     *        '                                           * 3',I8,/,
     *        '                                           * 4',I8,/,
     *        '                                           * 5',I8,/,
     *        '                                           * 6',I8,/,
     *        '                                           * 7',I8,/,
     *        '                                           * 8',I8,/,
     *        '               ERROR LOG OVERFLOW COUNT       ',I8,/)
C
C     GO TO READ ANOTHER BLOCK
C
        GOTO 10
C
480   CONTINUE
        IF (BLOCK.NE.8) GOTO 500
C
C     IF NO EPHMERIS DATA DOES NOT KEEP THE DATA SO NO NEED TO
C              INFORM THE USER
C
        IF(.NOT.SAVE) GOTO 10
C
C*****************************************************************
C**   TRACKING CONFIGURATION                                    **
C*****************************************************************
C
C     COMPUTES THE DATE
C
        CALL SUB(FPI(2),DAY,HOUR,MIN,SEC)
        DAY=DAY+STDAY
C
C
        WRITE(6,481) MONTH,DAY,YEAR,HOUR,MIN,SEC
481   FORMAT(/,'        ********************************************',/,
     *        '        **       TRACKING CONFIGURATION AT         **',/,
     *        '        **',9X,2(I2,1X),I4,2X,2(I2,':'),F5.2,8X,'**',/,
     *        '        ********************************************',/)
C
        WRITE (6,482) FPI(1),(FPI(I),I=3,NFI),(INTG(I),I=1,NII)
 482  FORMAT(' PSEUDORANGE FTF OF VALIDITY     SEC          ',E22.14,/,
     * ' PREDETECTION BANDWHITHS   HZ       FREQUENCY,TRACER',/,
     *  2(4E20.14,/)),//,
     * ' TRACKING LOOP BANDWHITHS  HZ       FREQUENCY,TRACER',/,
     * 4( 4E20.14,/)),/,
     *  ' LOOP ROUND TRIP CALIBRACION DELAYS IN SECONDS ',/,
     *'        INCLUDING PRE-ANTENNA',/,' L1 ',E20.14,' L2 ',E20.14,//,
     *  ' LOOP ROUND TRIP CALIBRACION DELAYS IN SECONDS ',/,
     *  '              (INTERNAL TO RFM)',/,' L1 ',E20.14,' L2 ',E20.14,//,
     *  ' SV PRN ID OF EACH TRACER ',/,4I15,//,
     *  ' ANTENA INDICATOR/TRACER',/,4I15,//,
     *  ' CODE INDICATOR FLAG/TRACER',/,4I15,//)
C
C       TESTE IF THE CONSTELATION MATCHES THE EXISTING EPHMERIS
C                          DATA
        DO 495 INDEX=1,NSAT
        IF(STAT(INDEX).EQ.INTG(INDEX)) GO TO 495
        WRITE(6,490) INDEX,STAT(INDEX),INTG(INDEX)
 490  FORMAT(////,' ****** *******  WARNING  ******* ******',//,
     * ' ACTUAL NAVIGATIONAL DATA FOR TRACER ',I2,' IS FROM SV ',I2,/,
     * ' TRACKING CONFIGURATION SHOWS SV ',I2,//)
 495  CONTINUE
C
C     GO TO READ ANOTHER BLOCK
C
        GOTO 10
C
500   CONTINUE
```

```
C*****************************************************************
C**   BLOCKS THAT THIS PROGRAM IS NOT PREPERED TO DECODE        **
C*****************************************************************
C
         WRITE(6,501)
501   FORMAT(//,'*********************************************',
     *         /,' **   FOUND A BLOCK THAT THIS PROGRAM IS NOT      **',
     *         /,' **   ABLE TO DECODE . BLOCK DATA IS DUMPED NEXT  **',
     *         /,' *********************************************')
         WRITE(6,520) BLK,BLOCK,NFI,NII,NCI
         IF (NFI.NE.0) WRITE(6,530) (FPI(I),I=1,NFI)
         IF (NII.NE.0) WRITE(6,540) (INTG(I),I=1,NII)
         IF (NCI.NE.0) WRITE(6,550) (CHI(I),I=1,NCI)
520   FORMAT(1X,A5,4I5)
530   FORMAT(1X,4E20.14)
540   FORMAT(1X,6I12)
550   FORMAT(1X,10(A8))
C
C     GO TO READ ANOTHER BLOCK
C
         GOTO 10
C
C******************************************************************
C
C     END OF PROGRAM
C
2000  CONTINUE
         STOP
         END
C
C******************************************************************
C        THIS SUBROUTINE WAS TAKEN FROM THE KALMN PROGRAM
C******************************************************************
C
         SUBROUTINE XYLLH
        G                  ( X , Y , Z , AG , ESQ ,
        R                    DLAT , DLOG , DHT,PI)
C THIS SUBROUTINE CONVERTS POSITION FROM THE EARTH-CENTERED CARTESIAN
C COORDINATE SYSTEM TO THE GEODETIC COORDINATE SYSTEM.
C X,Y,Z=ESTIMATE OF RECEIVER POSITION IN KM
C AG=SEMIMAJOR AXIS OF REF. ELLIPSOID(RADIUS OF EARTH) IN KM
C ESQ=ECCENTRICITY SQUARED OF REF. ELLIPSOID=(2.-1./OBL)/OBL
C DLAT=GEODETIC LATITUDE OF RECEIVER POSITION IN DEGREES
C DLOG=GEODETIC LONGITUDE OF RECEIVER POSITION IN DEGREES
C DHT=GEODETIC HEIGHT OF RECEIVER POSITION IN METERS
C PI VALUE OF PI COMPUTED IN DOUBLE PRECISION IN THE MAIN PROGRAM
C SINCE LAT=LAT(X,Y,Z,LAT) AND HT=HT(X,Y,LAT), AN ITERATIVE PROCEDURE
C IS NECESSARY TO DETERMINE THE VALUES OF LATITUDE AND HT.
C THE WORKING EQUATIONS ARE AS FOLLOWS:
C HT=(R/COS(LAT))-AG1 WHERE AG1=AG/(SQRT(1-ESQ*SIN(LAT)**2))
C TAN(LOG)=Y/X
C TAN(LAT)=((Z+(ESQ*SIN(LAT)*AG1)/R)
C
         DOUBLE PRECISION LT , LT1 , LG , R , EP ,AG1
         DOUBLE PRECISION X , Y , Z , AG , ESQ , DLAT , DLOG , DHT , PI
C
C           FIND LONGITUDE
         LG = DATAN2(Y,X)
         IF (LG .LT. 0.D0) LG = LG + (2. * PI)
         R=DSQRT(X**2+Y**2)
C
C A FIRST GUESS FOR LATITUDE WOULD BE ATAN(Z/R)
         LT1=DATAN(Z/R)
C
C           SOLVE FOR LATITUDE BY ITERATIONS
         DO 10 I=1,5
            AG1=AG/(DSQRT(1.D0-ESQ*DSIN(LT1)**2
            LT=DATAN((Z+(ESQ*DSIN(LT1)*AG1     R
            EP=DABS(LT-LT1)
            IF(EP.LE. .00000000100) GOTO 5
```

AD-A184 453 DYNAMIC POSITIONING AT SEA USING THE GLOBAL POSITIONING 2/2
SYSTEM(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA
A M EZEQUIEL JUN 87

UNCLASSIFIED F/G 17/7.2 NL



MICROCOPY RESOLUTION TEST CHART

```
          LT1 = LT
 10   CONTINUE
  5   AG1=AG/(DSQRT(1D0-ESQ*DSIN(LT1)**2))
C
C          FIND HEIGHT
         DHT=((R/DCOS(LT))-AG1)
C CONVERT DLAT AND DLOG FROM RADIANS TO DEGREES
         DLAT=LT*180.D0/PI
         DLOG=LG*180.D0/PI
         RETURN
         END
C
C********************************************************************
C   THIS SUBROUTINE CONVERTS DECIMAL DEGREES IN DEGREES MINUTES SECONDS
C********************************************************************
C
         SUBROUTINE DMS(DEC,LDEG,MIN,SEC)
C
         DOUBLE PRECISION DEC,XNUM,XMIN
C
         XNUM=DABS(DEC)
         LDEG=DINT(XNUM)
         XMIN=(XNUM-DFLOAT(LDEG))*60.D0
         MIN=DINT(XMIN)
         XNUM=(XMIN-DFLOAT(MIN))*60.D0
         SEC=SNGL(XNUM)
         IF (LDEG.GE.360) LDEG=LDEG-360
         RETURN
         END
C
C********************************************************************
C   THIS SUBROUTINE CONVERTS TIME TAG IN DAYS HOURS MINUTES SECONDS
C********************************************************************
C
         SUBROUTINE SUB(TT,DAY,HOUR,MIN,SEC)
         INTEGER DAY, HOUR, MIN
         DOUBLE PRECISION TIME,TT
         REAL SEC
         TIME=TT
         DAY = DINT(TIME / (24.D0*3600.D0))
         TIME = TIME - DFLOAT(DAY) * 24.D0 * 3600.D0
         HOUR = DINT(TIME / 3600.D0)
         TIME = TIME - DFLOAT(HOUR) * 3600.D0
         MIN = DINT(TIME / 60.D0)
         TIME = TIME - DFLOAT(MIN) * 60.D0
         SEC = SNGL(TIME)
         RETURN
         END
/*
//GO.FT06F001 DD SYSOUT=*
//GO.FT07F001 DD DSN=MSS.S0812.CVFICA.OUTPUT,DISP=SHR
//GO.FT08F001 DD DSN=MSS.S0812.GESAR.POS,DISP=SHR
//GO.FT31F001 DD DSN=MSS.S0812.CVDATA,DISP=SHR
//GO.FT50F001 DD DSN=MSS.S0812.GPS.TAPES.DATA(DL285),DISP=SHR
//             DD DSN=MSS.S0812.GPS.TAPES.DATA(DL284),DISP=SHR
//             DD DSN=MSS.S0812.GPS.TAPES.DATA(DL286),DISP=SHR
//             DD DSN=MSS.S0812.GPS.TAPES.DATA(DL287),DISP=SHR
//             DD DSN=MSS.S0812.GPS.TAPES.DATA(DL288),DISP=SHR
//             DD DSN=MSS.S0812.GPS.TAPES.DATA(DL289),DISP=SHR
//             DD DSN=MSS.S0812.GPS.TAPES.DATA(DL290),DISP=SHR
//             DD DSN=MSS.S0812.GPS.TAPES.DATA(DL291),DISP=SHR
//             DD DSN=MSS.S0812.GPS.TAPES.DATA(DL292),DISP=SHR
//
```

# APPENDIX F
# PROGRAM TRANSDUC GPS. SOURCE LISTING

```
//JOBTRANS     JOB (0812,9999),'EZEQUIEL',CLASS=C
//*MAIN        ORG=NPGVM1.0812P,LINES=(99),CARDS=(99)
//*FORMAT PR,DDNAME=GO.FT06F001,
//*FORMS=SEP1
//             EXEC FORTVCLG
//FORT.SYSIN   DD *
C
C    PROGRAM TRANSDUC GPS
C
C    AUTHOR: AUGUSTO EZEQUIEL
C    DATE: MARCH 30, 1987
C
C    DESCRIPTION:
C
C       THIS PROGRAMS TAKES EACH POSITION OF THE ANTENNA,
C       THE COMPUTED COURSE ( FILTERED OR NOT ) ,THE PITCH
C       AND ROLL DATA, AND COMPUTES THE POSITIONS OF THE
C       TRANSDUCER, APLYING THE SEVEN PARAMETER TRANSFORMATION
C       TO THE OFFSETS OF THE TRANSDUCER IN RELATION TO THE ANTENNA
C       CONSIDERED THE CENTER OF COORDINATE SYSTEM AND THEN ADDING
C       THE CORRECTIONS TO THE COORDINATES.
C
C       THE PROGRAM RUNS IN MVS
C
C       I/O SPECIFICATIONS:  SEE END OF THIS JOB.
C
C      THIS PROGRAM IS RESTRICT AS IS TO THE SEAFLOOR BENCHMARK
C      EXPERIMENT
C
C      THE PROGRAM WILL RUN WITH ANY AMOUNT OF DATA ONLY LIMITED TO DISK
C      SPACE
C
C      ANY BLANK LINES WILL TERMINATE THE PROGRAM  IN ERROR
C
C
C
        DOUBLE PRECISION XPOS,YPOS,TIME1,TIME2,TIME3,SECD,SECH,RATE
        DOUBLE PRECISION TIME4, TIME5
        DOUBLE PRECISION TT,DLAT,DLOG,DHT,X,Y,Z
        REAL COURSE,PITCH(2),ROLL(2),SEC1(2),SEC2,PIT,ROL,SEC3(2)
        REAL DX,DY,DZ,OFFX,OFFY,OFFZ,HEAD(2),LASEG,LOSEG
        INTEGER MONTH1(2),DAY1(2),YEAR1(2),HOUR1(2),MIN1(2)
        INTEGER MONTH2    ,DAY2    ,YEAR2    ,HOUR2    ,MIN2
        INTEGER MONTH3(2),DAY3(2),YEAR3(2),HOUR3(2),MIN3(2)
        INTEGER LADEG,LAMIN,LODEG,LOMIN, STDAY , NSAT
        CHARACTER*8 TITLE(10)
C
C      INITIALIZATION OF CONSTANTS
C
        SECH=3600.D0
        SECD=24.D0*SECH
C
        OFFX=-4.268
        OFFY=-2.955
        OFFZ=-9.502
C
C      READS THE TITLE FROM THE FILE
C
        READ(30,5,END=100)TITLE
        WRITE(6,5) TITLE
        READ(30,5,END=100)TITLE
```

```
      WRITE(6,5) TITLE
 5    FORMAT(10A8)
      READ(30,*,END=100) MONTH2,STDAY,YEAR2
      WRITE(6,6) MONTH2,STDAY,YEAR
 6    FORMAT(///,
     * ' DATE OF STARTING GPS WEEK (MONTH DAY YEAR) ',I3,I3,I5)
C
C     READS TWO SETS OF PITCH AND ROLL DATA
C
      READ(51,*,END=100) MONTH1(1),DAY1(1),YEAR1(1),HOUR1(1),MIN1(1),
     $                   SEC1(1),PITCH(1),ROLL(1)
      TIME1=DFLOAT(DAY1(1))*SECD+DFLOAT(HOUR1(1))*SECH
     $      + DFLOAT(MIN1(1))*60.D0+DBLE(SEC1(1))
C
      READ(51,*,END=100) MONTH1(2),DAY1(2),YEAR1(2),HOUR1(2),MIN1(2),
     $                   SEC1(2),PITCH(2),ROLL(2)
      TIME2=DFLOAT(DAY1(2))*SECD+DFLOAT(HOUR1(2))*SECH
     $      + DFLOAT(MIN1(2))*60.D0+DBLE(SEC1(2))
C
C     READS TWO SETS OF COURSE
C
      READ(52,END=100) MONTH3(1),DAY3(1),YEAR3(1),HOUR3(1),MIN3(1),
     $                   SEC3(1),HEAD(1)
      TIME4=DFLOAT(DAY3(1))*SECD+DFLOAT(HOUR3(1))*SECH
     $      + DFLOAT(MIN3(1))*60.D0+DBLE(SEC3(1))
C
      READ(52,END=100) MONTH3(2),DAY3(2),YEAR3(2),HOUR3(2),MIN3(2),
     $                   SEC3(2),HEAD(2)
      TIME5=DFLOAT(DAY3(2))*SECD+DFLOAT(HOUR3(2))*SECH
     $      + DFLOAT(MIN3(2))*60.D0+DBLE(SEC3(2))
C
C      READS ONE POSITION OF THE SHIP
C
 20    READ(50,END=100) TT , X ,Y,Z, DLAT , DLOB , DNT , NSAT
C
C     COMPUTES THE DATE
C
      CALL SUB(TT,DAY2,HOUR2,MIN2,SEC2)
      DAY2=DAY2+STDAY
C
C     CONVERTS LATITUDE TO DEGREES MINUTES AND SECONDS
C
      CALL DMS(DLAT,LADEG,LAMIN,LASEG)
C
C     CONVERTS LONGITUDE TO DEGREES MINUTES AND SECONDS
C              IN A RANGE 0 TO 180
      IF (DLOB.GT.180.D0) DLOB=360.D0-DLOB
C
      CALL DMS(DLOB,LODEG,LOMIN,LOSEG)
C
C     WRITE(6,24) LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG
C  24 FORMAT(' LAT, LON (DEG MIN SEC, DEG MIN SEG) ',2(2I4,1X,F7.4),/)
C
      TIME3=DFLOAT(DAY2)*SECD+DFLOAT(HOUR2)*SECH
     $      + DFLOAT(MIN2)*60.D0+DBLE(SEC2)
C
C      POSITION IN TIME BETWEEN THE TWO SETS OF PITCH AND ROLL DATA
C            AND THE TWO SETS OF COURSE DATA
  25 CONTINUE
C
C       POSITION TO EARLY FOR PITCH AND ROLL DATA
C
      IF(TIME3.GE.TIME1) GO TO 40
      WRITE(6,30) MONTH2,DAY2,YEAR2,HOUR2,MIN2,SEC2
  30 FORMAT(' PSN @ ',I2,1X,I2,1X,I4,1X,I2,1X,I2,1X,F4.1,
     $ ' REJECTED. NO PITCH AND ROLL DATA')
      GOTO 20
C
C       POSITION TO EARLY FOR PITCH AND ROLL DATA
C
```

```
   40 CONTINUE
        IF(TIME3.GE.TIME4) GO TO 60
        WRITE(6,50) MONTH2,DAY2,YEAR2,HOUR2,MIN2,SEC2
   50 FORMAT(' PSN @ ',I2,1X,I2,1X,I4,1X,I2,1X,I2,1X,F4.1,
      $ ' REJECTED. NO COURSE DATA')
        GOTO 20
C
C      POSITION LATER THAN THE SECOND SET OF PITCH AND ROLL DATA
C
   60 CONTINUE
        IF(TIME3.LE.TIME2) GOTO 70
C
C      MOVES THE PITCH AND ROLL DATA TO THE FIRST SET
C
        MONTH1(1)=MONTH1(2)
        DAY1(1)=DAY1(2)
        YEAR1(1)=YEAR1(2)
        HOUR1(1)=HOUR1(2)
        MIN1(1)=MIN1(2)
        SEC1(2)=SEC1(2)
        PITCH(1)=PITCH(2)
        ROLL(1)=ROLL(2)
        TIME1=TIME2
C
C      READS A SECOND SET OF PITCH AND ROLL DATA
C
        READ(51,*,END=100) MONTH1(2),DAY1(2),YEAR1(2),HOUR1(2),MIN1(2),
      $                     SEC1(2),PITCH(2),ROLL(2)
        TIME2=DFLOAT(DAY1(2))*SECD+DFLOAT(HOUR1(2))*SECH
      $        + DFLOAT(MIN1(2))*60.D0+DBLE(SEC1(2))
        GOTO 25
C
C
C      POSITION LATER THAN THE SECOND SET OF COURSE DATA
C
   70 CONTINUE
        IF(TIME3.LE.TIME5) GOTO 80
C
C      MOVES THE COURSE DATA TO THE FIRST SET
C
        MONTH3(1)=MONTH3(2)
        DAY3(1)=DAY3(2)
        YEAR3(1)=YEAR3(2)
        HOUR3(1)=HOUR3(2)
        MIN3(1)=MIN3(2)
        SEC3(2)=SEC3(2)
        HEAD(1)=HEAD(2)
        TIME4=TIME5
C
C      READS A SECOND SET OF PITCH AND ROLL DATA
C
        READ(52,END=100) MONTH3(2),DAY3(2),YEAR3(2),HOUR3(2),MIN3(2),
      $                     SEC3(2),HEAD(2)
        TIME5=DFLOAT(DAY3(2))*SECD+DFLOAT(HOUR3(2))*SECH
      $        + DFLOAT(MIN3(2))*60.D0+DBLE(SEC3(2))
        GOTO 25
C
C      POSITION WITHIN THE TWO SETS IN TIME
C
   80 RATE=(TIME3-TIME1)/(TIME2-TIME1)
        PIT=PITCH(1)+(PITCH(2)-PITCH(1))*RATE
        ROL=ROLL(1)+(ROLL(2)-ROLL(1))*RATE
        RATE=(TIME3-TIME4)/(TIME5-TIME4)
        COURSE=HEAD(1)+(HEAD(2)-HEAD(1))*RATE
C
C      COMPUTS THE CORRECTIONS AND THE POSITIONS OF THE TRANSDUCER
C
        CALL PTH(OFFX,OFFY,OFFZ,COURSE,PIT,ROL,DX,DY,DZ)
C
C      COMPUTES THE UTM COORDINATES
```

```
C
         CALL GPUTM(LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG,YPOS,XPOS)
C
         XPOS=XPOS+DX
         YPOS=YPOS+DY
C
C     CONVERTS BACK TO GP
C
         CALL UTMGP(YPOS,XPOS,LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG)
C
C     OUTPUTS THE RESULT
C
         WRITE(7) MONTH2,DAY2,YEAR2,HOUR2,MIN2,SEC2,
      #                       LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG,NSAT
C
C     WRITE(6,90) MONTH2,DAY2,YEAR2,HOUR2,MIN2,SEC2,
C    #                       LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG,NSAT
   90  FORMAT(2(1X,I2),1X,I4,2(1X,I2),1X,F4.1,2(1X,I3,1X,I2,1X,F7.4),I3)
C
C     READS ONE MORE POSITION
         GOTO 20
C
C     END OF PROGRAM
C
  100 CONTINUE
         STOP
         END
C
         SUBROUTINE PTH(XOFF,YOFF,ZOFF,COURSE,PITCH,ROLL,DX,DY,DZ)
C
C     THIS SUBROUTINE COMPUTES THE CORRECTIONS TO THE
C     COORDINATES DUE TO THE OFSET OF ANTENA IN RELATION
C     TO THE TRANSDUCER
C
         PI=ARCOS(-1.0)
         ROLL=ROLL*PI/180.
         PITCH=PITCH*PI/180.
         COURSE=COURSE*PI/180.
C
C     CHANGE SIGNAL OF ORIGINAL DATA TO MATCH THE RIGHT HAND
C     SYSTEM CONVECTION
C
         ROLL=-ROLL
C
         COSPHI= COS(ROLL)
         SINPHI= SIN(ROLL)
         COSK= COS(COURSE)
         SINK= SIN(COURSE)
         COSW= COS(PITCH)
         SINW= SIN(PITCH)
C
         DX = XOFF * COSPHI * COSK +
      $      YOFF * ( COSW * SINK + SINW * SINPHI * COSK  ) +
      $      ZOFF * ( SINW * SINK - COSW * SINPHI * COSK  )
C
         DY = XOFF * COSPHI * SINK * (-1.) +
      $      YOFF * ( COSW * COSK - SINW * SINPHI * SINK  ) +
      $      ZOFF * ( SINW * COSK + COSW * SINPHI * SINK  )
C
         DZ = XOFF * SINPHI -
      $      YOFF * (  SINW * COSPHI  ) +
      $      ZOFF * ( COSW * COSPHI  )
         RETURN
         END
C
C
C
         SUBROUTINE GPUTM(LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG,NORTH,EAST)
C
         DOUBLE PRECISION A,R,N,AP,BP,CP,DP,EP,S,R1,ESQ,ESQP,RM,RP,KO
```

```
      DOUBLE PRECISION R2,R3,R4,R5,P,P2,P3,P4,P5,P6,A6,B5,SINSEC
      DOUBLE PRECISION PHI,DLAM,NORTH,EAST,B,PHIMIN,PI,LON
      REAL LASEG,LOSEG
C
C    THIS SUBROUTINE COMPUTS THE UTM COORDINATES OF GP IN WGS 72
C    IN ZONE 10 CENTRAL MERIDIAN 123 00 00 W
C
      CM=-123.0D0
      PHI=DFLOAT(LADEG)+DFLOAT(LAMIN)/60.D0+DBLE(LASEG)/3600.D0
      LON=DFLOAT(LODEG)+DFLOAT(LOMIN)/60.D0+DBLE(LOSEG)/3600.D0
      LON=-LON
      DLAM=(LON-CM)*3600.0D0
C
      A=6378135.0D0
      R=298.26D0
C
      KO=0.9996D0
C
      B = A*(R-1.D0)/R
C
      N = (A-B)/(A+B)
      AP = A*((1.D0-N)+5.D0/4.D0*(N**2-N**3)+81.D0/64.D0*(N**4-N**5))
      BP = 3.D0/2.D0*A*((N-N**2)+7.D0/8.D0*(N**3-N**4)+55.D0/64.D0*N**5)
      CP = 15.D0/16.D0*A*(N**2-N**3+3.D0/4.D0*(N**4-N**5))
      DP = 35.D0/48.D0*A*(N**3-N**4+11.D0/16.D0*N**5)
      EP = 315.D0/512.D0*A*(N**4-N**5)
      PHIMIN = PHI*60.D0*2.90888208666D-4
C
      PI=DARCOS(-1.D0)
C
      PHI=PHI/180.D0*PI
C
      S = AP*PHIMIN-BP*DSIN(2.D0*PHI)+CP*DSIN(4.D0*PHI)
     $ - DP*DSIN(6.D0*PHI)+EP*DSIN(8.D0*PHI)
      R1 = KO*S
C
      SINSEC = (1.D0/3600.D0)/180.D0*PI
      SINSEC=DSIN(SINSEC)
C
      ESQ = (A**2-B**2)/A**2
      ESQP = ESQ/(1.D0-ESQ)
      RM = A*(1.D0-ESQ)/(DSQRT(1.D0-ESQ*DSIN(PHI)**2))**3
C
      RP = RM*(1.D0+ESQP*DCOS(PHI)**2)
      R2 = RP*DSIN(PHI)*DCOS(PHI)*SINSEC**2/2.D0*KO*1.D08
      R3 = SINSEC**4*RP*DSIN(PHI)*DCOS(PHI)**3/24.D0*(5.D0-DTAN(PHI)**2
     $ + 9.D0*ESQP*DCOS(PHI)**2+4.D0*ESQP*ESQP*DCOS(PHI)**4)*KO*1.D16
      R4 = RP*DCOS(PHI)*SINSEC*KO*1.D4
      R5 = SINSEC**3*RP*DCOS(PHI)**3/6.D0*(1.D0-DTAN(PHI)**2
     $   + ESQP*DCOS(PHI)**2)*KO*1.D12
C
      P = .0001D0*DLAM
      P2 = P**2
      P3 = P**3
      P4 = P**4
      P5 = P**5
      P6 = P**6
C
      A6 = P6*SINSEC**6*RP*DSIN(PHI)*DCOS(PHI)**5/720.D0
     $   * (61.D0-58.D0*DTAN(PHI)**2+DTAN(PHI)**4
     $   + 270.D0*ESQP*DCOS(PHI)**2-330.D0*ESQP*DSIN(PHI)**2)*KO*1.D24
      B5 = P5*SINSEC**5*RP*DCOS(PHI)**5/120.D0*(5.D0-18.D0*DTAN(PHI)**2
     $   + DTAN(PHI)**4+14.D0*ESQP*DCOS(PHI)**2
     $   - 58.D0*ESQP*DSIN(PHI)**2)*KO*1.D20
      NORTH=R1+R2*P2+R3*P4+A6
      EAST=(R4*P+R5*P3+B5)+500000.D0
      RETURN
      END
C
      SUBROUTINE UTMGP(NORTH,EAST,LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG)
```

```
C
      DOUBLE PRECISION A,R,N,B, BP,CP,DP,EP,S,R1,ESQ,ESQP,RM,RP,KO
      DOUBLE PRECISION R7,R8,R9,E5,Q,Q2,Q3,Q4,Q5,Q6,D6,AP,SINSEC
      DOUBLE PRECISION R10,DLAM,NORTH,EAST,RPHI,DPHI ,PHIMIN
      DOUBLE PRECISION EPRIME,DELTA,D6NUM,CM,PHI,LON,PI
      REAL LASEG,LOSEG
C
C     THIS SUBROUTINE COMPUTS THE UTM COORDINATES OF GP IN WGS 72
C     IN ZONE 10 CENTRAL MERIDIAN 123 00 00 W
C
      CM=-123.0D0
C
      A=6378135.0D0
      R=298.26D0
C
      KO=0.9996D0
C
      PI=DARCOS(-1.D0)
      B = A*(R-1.D0)/R
C
      N = (A-B)/(A+B)
      AP = A*((1.D0-N)+5.D0/4.D0*(N**2-N**3)+81.D0/64.D0*(N**4-N**5))
      BP = 3.D0/2.D0*A*((N-N**2)+7.D0/8.D0*(N**3-N**4)+55.D0/64.D0*N**5)
      CP = 15.D0/16.D0*A*(N**2-N**3+3.D0/4.D0*(N**4-N**5))
      DP = 35.D0/48.D0*A*(N**3-N**4+11.D0/16.D0*N**5)
      EP = 315.D0/512.D0*A*(N**4-N**5)
C
C     FIRST APROXIMATION OF PHI
C
      PHI=NORTH/30.8D0/3600.D0
C
C     COMPUT TRUE MERIDIONAL DIST AND APROXIMATE PHI
C
      DO 100 I=1,8
      PHIMIN=PHI*60.D0*2.908882086660-4
      RPHI=PHI/180.D0*PI
      S = AP*PHIMIN-BP*DSIN(2.D0*RPHI)+CP*DSIN(4.D0*RPHI)
     $    -DP*DSIN(6.D0*RPHI)+EP*DSIN(8.D0*RPHI)
      R1 = KO*S
      DELTA=NORTH-R1
      PHI=(DELTA/30.8/3600.)+PHI
  100 CONTINUE
      RPHI=PHI/180.D0*PI
C
C
      SINSEC = (1.D0/360000)/180.D0*PI
      SINSEC = DSIN(SINSEC)
C
      ESQ = (A**2-B**2)/A**2
      ESQP = ESQ/(1.D0-ESQ)
      RM = A*(1.D0-ESQ)/(DSQRT(1.D0-ESQ*DSIN(RPHI)**2))**3
C
      RP = RM*(1.D0+ESQP*DCOS(RPHI)**2)
      R7=(DTAN(RPHI)/(2.D0*RP**2*SINSEC))*(1.D0+ESQP*DCOS(RPHI)**2)
     $    *1.D12/KO**2
      R8=(DTAN(RPHI)/(24.D0*RP**4*SINSEC))*(5.D0+3.D0*DTAN(RPHI)**2
     $   +6.D0*ESQP*DCOS(RPHI)**2-6.D0*ESQP*DSIN(RPHI)**2-3.D0*ESQP**2
     $   *DCOS(RPHI)**4-9.D0*ESQP**2*DCOS(RPHI)**2*DSIN(RPHI)**2)
     $   *1.D24/KO**4
      R9=1.D0/DCOS(RPHI)/(RP*SINSEC)*1.D6/KO
      R10=1.D0/DCOS(RPHI)/(6.D0*RP**3*SINSEC)*(1.D0+2.D0*DTAN(RPHI)**2
     $    +ESQP*DCOS(RPHI)**2)*1.D18/KO**3
C
      EPRIME=EAST-500000.D0
      Q = .000001D0*EPRIME
      Q2 = Q**2
      Q3 = Q**3
      Q4 = Q**4
      Q5 = Q**5
```

```
      Q6 = Q**6
      D6NUM=Q6*DTAN(RPHI)
      D6=(D6NUM)/(720.D0*RP**6*SINSEC)*(61.D0+90.D0*DTAN(RPHI)**2
     $   +45.D0*DTAN(RPHI)**4+107.D0*ESQP*DCOS(RPHI)**2
     $   -162.D0*ESQP*DSIN(RPHI)**2-45.D0*ESQP*DTAN(RPHI)**2
     $   *DSIN(RPHI)**2)*1.D36/KO**6
      E5=(Q5*1.D0/DCOS(RPHI))/(120.D0*RP**5*SINSEC)*(5.D0+28.D0
     $   *DTAN(RPHI)**2+24.D0*DTAN(RPHI)**4+6.D0*ESQP*DCOS(RPHI)**2
     $   +8.D0*ESQP*DSIN(RPHI)**2)*1.D30/KO**5
C
      DPHI=(-R7*Q2+R8*Q4-D6)/3600.D0
      DLAM=(R9*Q-R10*Q3+E5)/3600.D0
      PHI=PHI+DPHI
      LON=CM+DLAM
      CALL DMS(PHI,LADEG,LAMIN,LASEG)
      CALL DMS(LON,LODEG,LOMIN,LOSEG)
      RETURN
      END
C
      SUBROUTINE DMS(DEC,LDEG,MIN,SEC)
C
      DOUBLE PRECISION DEC,XNUM,XMIN
C
      XNUM=DABS(DEC)
      LDEG=DINT(XNUM)
      XMIN=(XNUM-DFLOAT(LDEG))*60.D0
      MIN=DINT(XMIN)
      XNUM=(XMIN-DFLOAT(MIN))*60.D0
      SEC=SNGL(XNUM)
      IF (LDEG.GE.360) LDEG=LDEG-360
      RETURN
      END
C
      SUBROUTINE SUB(TT,DAY,HOUR,MIN,SEC)
      INTEGER DAY, HOUR, MIN
      DOUBLE PRECISION TIME,TT
      REAL SEC
      TIME=TT
      DAY = DINT(TIME / (24.D0*3600.D0))
      TIME = TIME - DFLOAT(DAY) * 24.D0 * 3600.D0
      HOUR = DINT(TIME / 3600.D0)
      TIME = TIME - DFLOAT(HOUR) * 3600.D0
      MIN = DINT(TIME / 60.D0)
      TIME = TIME - DFLOAT(MIN) * 60.D0
      SEC = SNGL(TIME)
      RETURN
      END
/*
//GO.FT06F001 DD SYSOUT=*
//GO.FT07F001 DD DSN=MSS.S0812.GPS.TRANSDUC.POS,DISP=SHR
//GO.FT30F001 DD DSN=MSS.S0812.CVDATA,DISP=SHR
//GO.FT50F001 DD DSN=MSS.S0812.GPS.ANTENNA.POS,DISP=SHR
//GO.FT51F001 DD DSN=MSS.S0812.PITROLL,DISP=SHR
//GO.FT52F001 DD DSN=MSS.S0812.SDAS.COURSE,DISP=SHR
//
```

# APPENDIX G

# PROGRAM COMPARE POSITION. SOURCE LISTING

```
//JOBCOMPA    JOB (0812,9999),'EZEQUIEL',CLASS=C
//*MAIN       ORG=NPGVM1.0812P,LINES=(99),CARDS=(99)
//*FORMAT PR,DDNAME=GO.FT06F001,
//*DEST=NPGBACH
//            EXEC FORTVCLG
//FORT.SYSIN  DD *
C
C    PROGRAM COMPARE POSITION
C
C    AUTHOR: AUGUSTO EZEQUIEL
C    DATE: MARCH 27, 1987
C
C    DESCRIPTION:
C
C       THIS PROGRAMS TAKES EACH GPS POSITION , FINDS THE
C       CORRESPONDING POSITION USING THE MR FALCON, COMPUTES THE
C       X, Y AND RADIAL DIFFERENCES AND PRINTS THE DATE TIME TAG
C       GEOGRAPHIC POSITIONS AND DIFFERENCES. THIS PROGRAM READS
C       THE PERIODS TO COMPARE THE DATA FROM A SEPARATE FILE.
C
C       THE PROGRAM RUNS IN MVS
C
C       I/O SPECIFICATIONS:  SEE END OF THIS JOB.
C
C      THIS PROGRAM IS RESTRICT AS IS TO THE SEAFLOOR BENCHMARK
C      EXPERIMENT
C
C      THE PROGRAM WILL RUN WITH ANY AMOUNT OF DATA ONLY LIMITED TO DISK
C      SPACE
C
C      ANY BLANK LINES WILL TERMINATE THE PROGRAM  IN ERROR
C
C
C
        DOUBLE PRECISION XPOS(3),YPOS(3),TIME(5),SECD,SECH,RATE
        DOUBLE PRECISION DIFX,DIFY,DIST,XNEW,YNEW
        REAL SEC(5),LASEG(3),LOSEG(3)
        INTEGER MONTH(5),DAY(5),YEAR(5),HOUR(5),MIN(5),NSAT
        INTEGER LADEG(3),LAMIN(3),LODEG(3),LOMIN(3),LINE,LOOP,INDEX
C
C      INITIALIZATION OF CONSTANTS
C
        SECH=3600.D0
        SECD=24.D0*SECH
        DIFX=0.0
        DIFY=0.0
        DIST=0.0
C
C      INPUTS THE NUMBER OF PERIODS TO COMPARE THE DATA
C
        READ(25,*,END=100) LOOP
C
C      LOOP OF THE PROGRAM TO THE NUMBER OF TIMES DESIRED
C
        DO 1000 INDEX = 1, LOOP
C
        LINE=60
        REWIND(30)
        REWIND(50)
C
        READ(25,*,END=100) MONTH(4),DAY(4),YEAR(4),HOUR(4),MIN(4),SEC(4)
```

```
     $ ,MONTH(5),DAY(5),YEAR(5),HOUR(5),MIN(5),SEC(5)
C
C     STARTING TIME
C
        TIME(4)=DFLOAT(DAY(4))*SECD+DFLOAT(HOUR(4))*SECH
     $        + DFLOAT(MIN(4))*60.D0+DBLE(SEC(4))
C
C     ENDING TIME
C
        TIME(5)=DFLOAT(DAY(5))*SECD+DFLOAT(HOUR(5))*SECH
     $        + DFLOAT(MIN(5))*60.D0+DBLE(SEC(5))
C
C     READS TWO MR FALCON POSITIONS
C
   10 READ(30,END=100) MONTH(1),DAY(1),YEAR(1),HOUR(1),MIN(1),SEC(1),
     $              LADEG(1),LAMIN(1),LASEG(1),LODEG(1),LOMIN(1),LOSEG(1)
        TIME(1)=DFLOAT(DAY(1))*SECD+DFLOAT(HOUR(1))*SECH
     $        + DFLOAT(MIN(1))*60.D0+DBLE(SEC(1))
C
C     POSITIONS THE FIRST POSITION INSIDE THE PERIOD. THE REST, OF THE
C      PROGRAM WILL ADJUST BY IT SELF
C
        IF( TIME(1).LT.TIME(4) ) GO TO 10
C
C
        READ(30,END=100) MONTH(2),DAY(2),YEAR(2),HOUR(2),MIN(2),SEC(2),
     $              LADEG(2),LAMIN(2),LASEG(2),LODEG(2),LOMIN(2),LOSEG(2)
        TIME(2)=DFLOAT(DAY(2))*SECD+DFLOAT(HOUR(2))*SECH
     $        + DFLOAT(MIN(2))*60.D0+DBLE(SEC(2))
C
C     COMPUTES THE UTM COORDINATES
C
        CALL GPUTM(LADEG(1),LAMIN(1),LASEG(1),LODEG(1),LOMIN(1),LOSEG(1),
     $             YPOS(1),XPOS(1))
        CALL GPUTM(LADEG(2),LAMIN(2),LASEG(2),LODEG(2),LOMIN(2),LOSEG(2),
     $             YPOS(2),XPOS(2))
C
C      READS GPS POSITION OF THE SHIP
C
   20 READ(50,END=100) MONTH(3),DAY(3),YEAR(3),HOUR(3),MIN(3),SEC(3),
     $         LADEG(3),LAMIN(3),LASEG(3),LODEG(3),LOMIN(3),LOSEG(3),NSAT
        CALL GPUTM(LADEG(3),LAMIN(3),LASEG(3),LODEG(3),LOMIN(3),LOSEG(3),
     $             YPOS(3),XPOS(3))
C
        TIME(3)=DFLOAT(DAY(3))*SECD+DFLOAT(HOUR(3))*SECH
     $        + DFLOAT(MIN(3))*60.D0+DBLE(SEC(3))
C
C     POSITION OUTSIDE OF THE PERIOD
C      PROGRAM WILL PICK ANOTHER PERIOD
C
        IF( TIME(3).GT.TIME(5) ) GO TO 1000
C
C      POSITION IN TIME BETWEEN THE TWO MR FALCON POSITIONS
C
   25 CONTINUE
C
C        POSITION TO EARLY FOR MR FALCON DATA
C
        IF(TIME(3).GE.TIME(1)) GO TO 40
C*    WRITE(6,30) MONTH(3),DAY(3),YEAR(3),HOUR(3),MIN(3),SEC(3)
C* 30 FORMAT(' GPS PSN @ ',I2,1X,I2,1X,I4,1X,I2,1X,I2,1X,F4.1,
C*    $ ' REJECTED. NO MR FALCON DATA')
        GOTO 20
C
C     POSITION LATER THAN THE SECOND MR FALCON POSITION
C
   40 CONTINUE
        IF(TIME(3).LE.TIME(2)) GOTO 70
C
C     MOVES THE SECOND MR FALCON POSITION TO THE FIRST SET
```

```
C
      MONTH(1)=MONTH(2)
      DAY(1)=DAY(2)
      YEAR(1)=YEAR(2)
      HOUR(1)=HOUR(2)
      MIN(1)=MIN(2)
      SEC(2)=SEC(2)
      TIME(1)=TIME(2)
      LADEG(1)=LADEG(2)
      LAMIN(1)=LAMIN(2)
      LASEG(1)=LASEG(2)
      YPOS(1)=YPOS(2)
      LODEG(1)=LODEG(2)
      LOMIN(1)=LOMIN(2)
      LOSEG(1)=LOSEG(2)
      XPOS(1)=XPOS(2)
C
C     READS A SECOND SET OF MR FALCON DATA
C
      READ(30,END=100) MONTH(2),DAY(2),YEAR(2),HOUR(2),MIN(2),SEC(2),
     $            LADEG(2),LAMIN(2),LASEG(2),LODEG(2),LOMIN(2),LOSEG(2)
      TIME(2)=DFLOAT(DAY(2))*SECD+DFLOAT(HOUR(2))*SECH
     $      + DFLOAT(MIN(2))*60.D0+DBLE(SEC(2))
      CALL GPUTM(LADEG(2),LAMIN(2),LASEG(2),LODEG(2),LOMIN(2),LOSEG(2),
     $          YPOS(2),XPOS(2))
      GOTO 25
C
C     GPS POSITION WITHIN THE TWO MR FALCON POSITIONS
C
   70 RATE=(TIME(3)-TIME(1))/(TIME(2)-TIME(1))
C
      XNEW=XPOS(1)+(XPOS(2)-XPOS(1))*RATE
      YNEW=YPOS(1)+(YPOS(2)-YPOS(1))*RATE
C
      DIFX=XPOS(3)-XNEW
      DIFY=YPOS(3)-YNEW
      DIST=DSQRT(DIFX**2+DIFY**2)
C
C     OUTPUTS THE RESULT
C
C
      IF (LINE.LT.60) GO TO 85
      WRITE(6,80)
   80 FORMAT(1H1,/,17X,'DIFFERENCES BETWEEN GPS AND MR FALCON POSITIONS'
     $ ,//,29X,'AVOIDING SV11'                           ,
     $ ,//,4X,'DATE',6X,'TIME',09X,'LATITUDE',7X,'LONGITUDE',
     $ 12X,'(METERS)',9X,'#',/,2X,'M',2X,'D',1X,'YEAR',1X,'HH',
     $ 1X,'MM',1X,'SS.S',2X,'DD',1X,'MM',1X,'SS.SSSS',3X,'DDD',1X,
     $ 'MM',1X,'SS.SSSS',5X,'DX',5X,'DY',5X,'DIST.',1X,'SAT.',/)
       LINE=0
   85 LINE=LINE+1
      WRITE(6,90) MONTH(3),DAY(3),YEAR(3),HOUR(3),MIN(3),SEC(3),
     $            LADEG(3),LAMIN(3),LASEG(3),LODEG(3),LOMIN(3),LOSEG(3),
     $            DIFX,DIFY,DIST,NSAT
   90 FORMAT(2(1X,I2),1X,I4,1X,I2,1X,I2,1X,F4.1,1X,I3,1X,I2,1X,F7.4,
     $ ' N',1X,I3,1X,I2,1X,F7.4,' W',1X,F6.2,1X,F6.2,1X,F7.2,1X,I2)
C
C     READS ONE MORE POSITION
      GOTO 20
C
C     END OF PROGRAM
C
 1000 CONTINUE
  100 CONTINUE
      STOP
      END
C
C
      SUBROUTINE GPUTM(LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG,NORTH,EAST)
C
```

```
      DOUBLE PRECISION A,R,N,AP,BP,CP,DP,EP,S,R1,ESQ,ESQP,RM,RP,KO
      DOUBLE PRECISION R2,R3,R4,R5,P,P2,P3,P4,P5,P6,A6,B5,SINSEC
      DOUBLE PRECISION PHI,DLAM,NORTH,EAST,B,PHIMIN,PI,LON
      INTEGER LADEG,LAMIN,LODEG,LOMIN
      REAL LASEG,LOSEG
C
C    THIS SUBROUTINE COMPUTS THE UTM COORDINATES OF GP IN WGS 72
C    IN ZONE 10 CENTRAL MERIDIAN 123 00 00 W
C
      CM=-123.0D0
      PHI=DFLOAT(LADEG)+DFLOAT(LAMIN)/60.D0+DBLE(LASEG)/3600.D0
      LON=DFLOAT(LODEG)+DFLOAT(LOMIN)/60.D0+DBLE(LOSEG)/3600.D0
      LON=-LON
      DLAM=(LON-CM)*3600.0D0
C
      A=6378135.0D0
      R=298.26D0
C
      KO=0.9996D0
C
      B = A*(R-1.D0)/R
C
      N = (A-B)/(A+B)
      AP = A*((1.D0-N)+5.D0/4.D0*(N**2-N**3)+81.D0/64.D0*(N**4-N**5))
      BP = 3.D0/2.D0*A*((N-N**2)+7.D0/8.D0*(N**3-N**4)+55.D0/64.D0*N**5)
      CP = 15.D0/16.D0*A*(N**2-N**3+3.D0/4.D0*(N**4-N**5))
      DP = 35.D0/48.D0*A*(N**3-N**4+11.D0/16.D0*N**5)
      EP = 315.D0/512.D0*A*(N**4-N**5)
      PHIMIN = PHI*60.D0*2.908882086660-4
C
      PI=DARCOS(-1.D0)
C
      PHI=PHI/180.D0*PI
C
      S = AP*PHIMIN-BP*DSIN(2.D0*PHI)+CP*DSIN(4.D0*PHI)
     $  - DP*DSIN(6.D0*PHI)+EP*DSIN(8.D0*PHI)
      R1 = KO*S
C
      SINSEC = (1.D0/3600.D0)/180.D0*PI
      SINSEC=DSIN(SINSEC)
C
      ESQ = (A**2-B**2)/A**2
      ESQP = ESQ/(1.D0-ESQ)
      RM = A*(1.D0-ESQ)/(DSQRT(1.D0-ESQ*DSIN(PHI)**2))**3
C
      RP = RM*(1.D0+ESQP*DCOS(PHI)**2)
      R2 = RP*DSIN(PHI)*DCOS(PHI)*SINSEC**2/2.D0*KO*1.D08
      R3 = SINSEC**4*RP*DSIN(PHI)*DCOS(PHI)**3/24.D0*(5.D0-DTAN(PHI)**2
     $ + 9.D0*ESQP*DCOS(PHI)**2+4.D0*ESQP*ESQP*DCOS(PHI)**4)*KO*1.D16
      R4 = RP*DCOS(PHI)*SINSEC*KO*1.D4
      R5 = SINSEC**3*RP*DCOS(PHI)**3/6.D0*(1.D0-DTAN(PHI)**2
     $   + ESQP*DCOS(PHI)**2)*KO*1.D12
C
      P = .0001D0*DLAM
      P2 = P**2
      P3 = P**3
      P4 = P**4
      P5 = P**5
      P6 = P**6
C
      A6 = P6*SINSEC**6*RP*DSIN(PHI)*DCOS(PHI)**5/720.D0
     $   * (61.D0-58.D0*DTAN(PHI)**2+DTAN(PHI)**4
     $   + 270.D0*ESQP*DCOS(PHI)**2-330.D0*ESQP*DSIN(PHI)**2)*KO*1.D24
      B5 = P5*SINSEC**5*RP*DCOS(PHI)**5/120.D0*(5.D0-18.D0*DTAN(PHI)**2
     $   + DTAN(PHI)**4+14.D0*ESQP*DCOS(PHI)**2
     $   - 58.D0*ESQP*DSIN(PHI)**2)*KO*1.D20
      NORTH=R1+R2*P2+R3*P4+A6
      EAST=(R4*P+R5*P3+B5)+500000.D0
      RETURN
      END
```

```
      END
/*
//GO.FT06F001 DD SYSOUT=*
//GO.FT25F001 DD DSN=MSS.S0812.PERIODS.COMPARE,DISP=SHR
//GO.FT30F001 DD DSN=MSS.S0812.FALCON.TRANSDUC.POS,DISP=SHR
//GO.FT50F001 DD DSN=MSS.S0812.GPS.TRANSDUC.POS,DISP=SHR
//
```

# APPENDIX H
## PROGRAM COMPARE PLOT. SOURCE LISTING

```
//EZEQUIEL     JOB (0812,9999),'EZEQUIEL',CLASS=C
//             EXEC FRTVCLGP
//FORT.SYSIN   DD *
C
C     PROGRAM COMPARE PLOT
C
C     RUNS IN FORTRAN VS
C
C     AUTHOR:  AUGUSTO EZEQUIEL
C
C     DATE : 31 MARCH 1987
C
C     THIS PROGRAM MAKES A PLOT OF THE POSITIONS OF THE SHIP
C     USING  GPS AND MR FALCON POSITIONS OF THE TRANSDUCER
C
C
        DOUBLE PRECISION XPOS,YPOS,XLEFT,YLEFT,TIME(4),SECD,SECH
        REAL SEC(3),XPLT,YPLT,BLXH,BLYH,SCALE,VALUE,LASEG,LOSEG
        REAL YORG,XORG
        INTEGER MONTH(3),YEAR(3),DAY(3),HOUR(3),MIN(3)
        INTEGER IPEN,LADEG,LAMIN,LODEG,LOMIN
        INTEGER IO,LOOP,INDEX
C
C     DIMENSIONS OF SHEET, LEFT CORNER AND SCALES
C
        BLXH=15.
        BLYH=20.5
        SCALE=1./5000.
        XORG=0.0
        YORG=-25.0
C
C     INITIALIZATION OF CONSTANTS
C
        TIME(4)=0.D0
        SECH=3600.D0
        SECD=24.D0*SECH
C
C     PLOTTER INITIALIZATION
C
        CALL PLOTS (0,0,0)
C
C     READS THE AMOUNT OF PERIODS TO COMPARE
C
        READ(30,*) LOOP
C
        DO 100 INDEX=1,LOOP
C
C     READS THE PERIODS AND INFERIOR LEFT CORNER OF EACH AREA
C
        READ(30,*) MONTH(1),DAY(1),YEAR(1),HOUR(1),MIN(1),SEC(1)
     $ ,MONTH(2),DAY(2),YEAR(2),HOUR(2),MIN(2),SEC(2), XLEFT,YLEFT
C
C     STARTING TIME
C
        TIME(1)=DFLOAT(DAY(1))*SECD+DFLOAT(HOUR(1))*SECH
     $       + DFLOAT(MIN(1))*60.D0+DBLE(SEC(1))
C
C     ENDING TIME
C
        TIME(2)=DFLOAT(DAY(2))*SECD+DFLOAT(HOUR(2))*SECH
     $       + DFLOAT(MIN(2))*60.D0+DBLE(SEC(2))
```

```
C
C      POSITIONS THE PEN IN THE ORIGIN
C
         YORG=-YORG
         XORG=25.0*(1-(-1)**INDEX)/2
         IF(INDEX.EQ.2) XORG=0
         CALL PLOT (XORG,YORG,-3)
C
C     GRID
C
         CALL PLOT (0.1,0.1,3)
         CALL PLOT (0.1,BLYH-0.1,2)
         CALL PLOT (BLXH-0.1,BLYH-0.1,2)
         CALL PLOT (BLXH-0.1,0.1,2)
         CALL PLOT (0.1,0.1,2)
C
C     SCALE
C
         CALL METER(SCALE)
C
C     TITLE
C
         CALL SYMBOL(08.1,19.2,0.20,29HSEAFLOOR BENCHMARK EXPERIMENT,0.,29)
C
         CALL SYMBOL(08.1,18.8,0.20,29H          PHASE II           ,0.,29)
C
         CALL SYMBOL(08.1,18.4,0.20,29H       16 AUGUST 1986        ,0.,29)
C
         CALL SYMBOL(08.1,18.0,0.20,29HAVOIDING SV11. NO CONSTRAIN  ,0.,29)
C
         CALL SYMBOL(01.0,03.375,0.15,3,0.,-1)
         CALL SYMBOL(1.20,03.3,0.15,29HMR FALCON TRANDUCER POSITIONS,0.,29)
C
         CALL SYMBOL(01.0,03.075,0.15,11,0.,-1)
         CALL SYMBOL(1.20,03.0,0.15,29HGPS TRANDUCER POSITIONS      ,0.,29)
C
C     SETS SYMBOL FOR MINI RANGER POSITIONS
C
         ISN=3
C
C     REWINDS THE FILES
C
         REWIND(31)
         REWIND(32)
C
C     LOOP FOR THE TYPES OF POSITION
C
         DO 80 IO=31,32
C
C     SETS PEN UP
C
         IPEN=3
C
C     LOOP WITHIN ONE TYPE OF POSITION
C
   10 CONTINUE
C
C     READ THE DATA
C
         READ(IO,END=50)MONTH(3),DAY(3),YEAR(3),HOUR(3),
       $ MIN(3),SEC(3),LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG
C
C     COMPUTES THE UTM COORDINATES
C
         CALL GPUTM(LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG,YPOS,XPOS)
C
C     COMPUTES THE TIME IN SECS
C
         TIME(3)=DFLOAT(DAY(3))*SECD+DFLOAT(HOUR(3))*SECH
       $       + DFLOAT(MIN(3))*60.D0+DBLE(SEC(3))
```

```
C
C     TESTS IF WITHIN THE PERIOD
C
         IF(TIME(3).GT.TIME(2)) GOTO 50
         IF(TIME(3).LT.TIME(1)) GOTO 10
C
C     COMPUTES THE PLOTTER COORDINATES
C
         XPLT=(XPOS-XLEFT)*SCALE*100.
         YPLT=(YPOS-YLEFT)*SCALE*100.
C
C     TESTE IF INSIDE AREA
C
         IF(XPLT.LT.0.) GOTO 30
         IF(YPLT.LT.0.) GOTO 30
         IF(XPLT.GT.BLXH) GOTO 30
         IF(YPLT.GT.BLYH) GOTO 30
C
C     TESTS IF POSITIONS ARE AWAY MORE THEN 10 SECS IN TIME
C
         IF(TIME(3)-TIME(4).GT.10.D0) IPEN=3
         TIME(4)=TIME(3)
C
C     PLOTS THE POSITION
C
         CALL PLOT(XPLT,YPLT,IPEN)
         IPEN=2
C
C     PLOTS THE TIME EVERY  MINUTE
C
         IF(IFIX(SEC(3)).GT.0) GO TO 10
         VALUE=FLOAT(HOUR(3))*100+FLOAT(MIN(3))
         CALL NUMBER(XPLT+0.15,YPLT+0.15,0.15,VALUE,0.,-1)
         CALL SYMBOL(XPLT,YPLT,0.15,ISN,0.,-1)
         GOTO 10
C
C     PEN UP WHILE THE POSITIONS ARE OUT OF THE SHEET
C
   30 IPEN=3
         GOTO 10
C
C     END OF PLOT
C
   50 CONTINUE
C
         ISN=11
         IPEN=3
   80 CONTINUE
  100 CONTINUE
         CALL PLOT(0.,0.,+999)
         STOP
         END
C
         SUBROUTINE METER(SCALE)
C
         XO=2.0
         YO=1.0
         CALL PLOT(XO,YO,-3)
C
         DO 10 J=1,12
         XP= FLOAT(J)-1.0
         CALL PLOT(XP,0.0,3)
         CALL PLOT(XP,0.25,2)
   10 CONTINUE
C
         DO 20 J=1,9
         XP=FLOAT(J)*0.1
         CALL PLOT(XP,0.0,3)
         CALL PLOT(XP,0.2,2)
```

```
      20 CONTINUE
C
         CALL PLOT(0.,0.0,3)
         CALL PLOT(11.,0.,2)
         CALL PLOT(0.,0.2,3)
         CALL PLOT(11.,.2,2)
C
         VALUE=1./SCALE/100.
         CALL NUMBER(-0.25,0.27,0.15,VALUE,0.0,-1)
         CALL NUMBER(0.95,0.27,0.15,0.0,0.0,-1)
         VALUE=5.0/SCALE/100.
         CALL NUMBER(5.775,0.27,0.15,VALUE,0.0,-1)
         VALUE=10.0/SCALE/100.
         CALL NUMBER(10.7,0.27,0.15,VALUE,0.0,-1)
         CALL SYMBOL(5.5,-0.25,.15,6HMETERS,0.0,6)
C
         CALL SYMBOL(10.0,12.0,1.5,62,0.0,-1)
         CALL SYMBOL(10.1,12.4,0.2,85,0.0,-1)
         XO=-XO
         YO=-YO
         CALL PLOT(XO,YO,-3)
C
         RETURN
         END
C
C
         SUBROUTINE GPUTM(LADEG,LAMIN,LASEG,LODEG,LOMIN,LOSEG,NORTH,EAST)
C
         DOUBLE PRECISION A,R,N,AP,BP,CP,DP,EP,S,R1,ESQ,ESQP,RM,RP,KO
         DOUBLE PRECISION R2,R3,R4,R5,P,P2,P3,P4,P5,P6,A6,B5,SINSEC
         DOUBLE PRECISION PHI,DLAM,NORTH,EAST,B,PHIMIN,PI,LON
         REAL LASEG,LOSEG
C
C     THIS SUBROUTINE COMPUTS THE UTM COORDINATES OF GP IN WGS 72
C     IN ZONE 10 CENTRAL MERIDIAN 123 00 00 W
C
         CM=-123.0D0
         PHI=DFLOAT(LADEG)+DFLOAT(LAMIN)/60.D0+DBLE(LASEG)/3600.D0
         LON=DFLOAT(LODEG)+DFLOAT(LOMIN)/60.D0+DBLE(LOSEG)/3600.D0
         LON=-LON
         DLAM=(LON-CM)*3600.0D0
C
         A=6378135.0D0
         R=298.26D0
C
         KO=0.9996D0
C
         B = A*(R-1.D0)/R
C
         N = (A-B)/(A+B)
         AP = A*((1.D0-N)+5.D0/4.D0*(N**2-N**3)+81.D0/64.D0*(N**4-N**5))
         BP = 3.D0/2.D0*A*((N-N**2)+7.D0/8.D0*(N**3-N**4)+55.D0/64.D0*N**5)
         CP = 15.D0/16.D0*A*(N**2-N**3+3.D0/4.D0*(N**4-N**5))
         DP = 35.D0/48.D0*A*(N**3-N**4+11.D0/16.D0*N**5)
         EP = 315.D0/512.D0*A*(N**4-N**5)
         PHIMIN = PHI*60.D0*2.908882086660-4
C
         PI=DARCOS(-1.D0)
C
         PHI=PHI/180.D0*PI
C
         S = AP*PHIMIN-BP*DSIN(2.D0*PHI)+CP*DSIN(4.D0*PHI)
        $  - DP*DSIN(6.D0*PHI)+EP*DSIN(8.D0*PHI)
         R1 = KO*S
C
         SINSEC = (1.D0/3600.D0)/180.D0*PI
         SINSEC=DSIN(SINSEC)
C
         ESQ = (A**2-B**2)/A**2
         ESQP = ESQ/(1.D0-ESQ)
```

```
      RM = A*(1.D0-ESQ)/(DSQRT(1.D0-ESQ*DSIN(PHI)**2))**3
C
      RP = RM*(1.D0+ESQP*DCOS(PHI)**2)
      R2 = RP*DSIN(PHI)*DCOS(PHI)*SINSEC**2/2.D0*KO*1.D8
      R3 = SINSEC**4*RP*DSIN(PHI)*DCOS(PHI)**3/24.D0*(5.D0-DTAN(PHI)**2
     $ + 9.D0*ESQP*DCOS(PHI)**2+4.D0*ESQP*ESQP*DCOS(PHI)**4)*KO*1.D16
      R4 = RP*DCOS(PHI)*SINSEC*KO*1.D4
      R5 = SINSEC**3*RP*DCOS(PHI)**3/6.D0*(1.D0-DTAN(PHI)**2
     $   + ESQP*DCOS(PHI)**2)*KO*1.D12
C
      P = .0001D0*DLAM
      P2 = P**2
      P3 = P**3
      P4 = P**4
      P5 = P**5
      P6 = P**6
C
      A6 = P6*SINSEC**6*RP*DSIN(PHI)*DCOS(PHI)**5/720.D0
     $   * (61.D0-58.D0*DTAN(PHI)**2+DTAN(PHI)**4
     $   + 270.D0*ESQP*DCOS(PHI)**2-330.D0*ESQP*DSIN(PHI)**2)*KO*1.D24
      B5 = P5*SINSEC**5*RP*DCOS(PHI)**5/120.D0*(5.D0-18.D0*DTAN(PHI)**2
     $   + DTAN(PHI)**4+14.D0*ESQP*DCOS(PHI)**2
     $   - 58.D0*ESQP*DSIN(PHI)**2)*KO*1.D20
      NORTH=R1+R2*P2+R3*P4+A6
      EAST=(R4*P+R5*P3+B5)+500000.D0
      RETURN
      END
/*
//GO.PLOTPARM DD  *
 &PLOT XMIN=0.,XMAX=300.,YMIN=0.,YMAX=51.,SCALE=1.,UNITS=2.540 &END
//GO.FT06F001 DD SYSOUT=*
//GO.FT30F001 DD DSN=MSS.S0812.PERIODS.COMPARE,DISP=SHR
//GO.FT31F001 DD DSN=MSS.S0812.FALCON.TRANSDUC.POS,DISP=SHR
//GO.FT32F001 DD DSN=MSS.S0812.GPS.TRANSDUC.POS,DISP=SHR
//
```

# APPENDIX I

## CONTROL FILE FOR KALMN2 PROGRAM. AS DEFINED BY BROWN(1986)

```
 585590.  700000.       1    6    10    4    1    1    0 0 0
 0  -2740.506 -4341.136 3772.0820 .8738E1 0.0 -3.0 0.0
6378.135 298.26
1.0 1.0 1.0 1.E-12 2.1 1.E-14 1.E-50 1.E-50 1.E-50 3.0 4.0 5.0
    1    0    1    0    0    0    0    1    0    0
0.000005 0.0
    1    1    0    0    0    0    1    0    1
980. 15. 75. 10.
0.75E-4 .75E-4 .75E-4 .1E-4   1.0 1.0 1.0 2.0 .1E-03 .1E-04
1.0 1.0 1.0 1.0 1.0 1.0 1.E-19 1.E-19 1.E-19
-.031
```

# APPENDIX J
# CONTROL FILE FOR CVFICA PROGRAM.

The first two lines may have a title up to 80 columns. The third line has the month day and year of the starting day of the GPS week. The fourth line has the number of satellites to be used, and other two constants are kept at zero. The last line has the estimate position in WGS 72 coordinates.

The next is the one used for this thesis:

```
          SEAFLOOR BENCH MARK   PHASE II
           R V POINT SUR 16 AUGUST 1986
8 10 1986
4     0.    0.
-2739.58  -4340.77  3773.14
```

# APPENDIX K

## CONTROL FILE FOR COMPARE POSITION AND PLOT PROGRAMS

The first lines has the number of periods to compare the data. This line must be followed by the same number of lines as periods are to compare. Each line the date time tags from the start and of the periods has the left inferior corner of the area corresponding to each period.

The next is the one used for this thesis:

```
11
8 16 1986 19 14 0.0  8 16 1986 19 20 3.0 567320.0 4038400.0
8 16 1986 19 20 0.0  8 16 1986 19 25 3.0 566920.0 4039000.0
8 16 1986 19 25 0.0  8 16 1986 19 30 3.0 566670.0 4039600.0
8 16 1986 19 30 0.0  8 16 1986 19 35 3.0 566270.0 4040200.0
8 16 1986 19 35 0.0  8 16 1986 19 40 3.0 566020.0 4040800.0
8 16 1986 19 47 0.0  8 16 1986 19 53 3.0 564920.0 4040950.0
8 16 1986 19 57 0.0  8 16 1986 20 05 3.0 564970.0 4040200.0
8 16 1986 20 07 0.0  8 16 1986 20 13 3.0 565570.0 4039500.0
8 16 1986 20 13 0.0  8 16 1986 20 20 3.0 566020.0 4039000.0
8 16 1986 20 20 0.0  8 16 1986 20 25 3.0 566420.0 4038500.0
8 16 1986 20 30 0.0  8 16 1986 20 37 3.0 565985.0 4038400.0
```

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